

# SELECTED NUTRIENTS AND PESTICIDES IN STREAMS OF THE EASTERN IOWA BASINS, 1970–95

Water-Resources Investigations Report 99–4028



# Selected Nutrients and Pesticides in Streams of the Eastern Iowa Basins, 1970–95

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# FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policy-makers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.

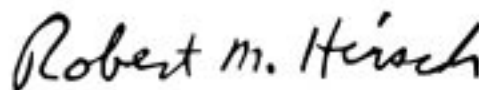
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch  
Chief Hydrologist

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## CONVERSION FACTORS, WATER-QUALITY UNITS, AND ABBREVIATIONS

Multiply	By	To obtain
<b>Length</b>		
inch	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<b>Area</b>		
square foot (ft <sup>2</sup> )	929.0	square centimeter (cm <sup>2</sup> )
square inch (in <sup>2</sup> )	6.452	square centimeter (cm <sup>2</sup> )
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
acre-foot (acre-ft)	1,233	cubic meter (m <sup>3</sup> )
<b>Volume</b>		
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m <sup>3</sup> )
cubic foot (ft <sup>3</sup> )	0.02832	cubic meter (m <sup>3</sup> )
cubic yard (yd <sup>3</sup> )	0.7646	cubic meter (m <sup>3</sup> )
<b>Flow</b>		
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m <sup>3</sup> /s)
<b>Mass</b>		
pound (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day (t/d)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)

**Temperature in degrees Celsius (°C)** may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

**Temperature in degrees Fahrenheit (°F)** may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

**pH** is the negative base-10 logarithm of the hydrogen ion activity, in moles per liter.

**One metric ton** is equal to 1,000 kilograms.

**Concentrations of chemical constituents** in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

**Water year** is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus, the year ending in September 30, 1995, is called “water year 1995.”

**These additional abbreviations are used in this report:**

<b><u>Abbreviation</u></b>	<b><u>Description</u></b>
ADAPS	Automated Data Processing System data base
EIWA	Eastern Iowa Basins
HAL	Health Advisory Level
IDNR	Iowa Department of Natural Resources
LOWESS	Locally Weighted Scatterplot Smooth
MCL	Maximum Contaminant Level
MPCA	Minnesota Pollution Control Agency
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water-Quality Assessment
NWIS	National Water Information System
STORET	STORage and RETrieval data base
SAS	Statistical Analysis System
UHL	University of Iowa Hygienic Laboratory
UIIHR	University of Iowa Institute of Hydraulic Research
USCOE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
NH <sub>3</sub>	Ammonia
NH <sub>4</sub> <sup>+</sup>	Ammonium
NO <sub>3</sub> <sup>-</sup>	Nitrate
N	Nitrogen
PO <sub>4</sub> <sup>3-</sup>	Orthophosphate
P	Phosphorus
µg/L	Micrograms per liter
mg/L	Milligrams per liter
°C	Degrees Celsius
°F	Degrees Fahrenheit
+	Upward trend
-	Downward trend

# Selected Nutrients and Pesticides in Streams of the Eastern Iowa Basins, 1970–95

By Douglas J. Schnoebelen, Kent D. Becher, Matthew W. Bobier *and* Thomas Wilton

## Abstract

Water-quality data from 17 surface-water monitoring sites were compiled for 1970 through 1995 and analyzed to determine historical water-quality conditions and possible trends in the Eastern Iowa Basins study unit as part of the U.S. Geological Survey's National Water-Quality Assessment Program. The Eastern Iowa Basins encompasses the Wapsipinicon, Cedar, Iowa, and Skunk River Basins and covers about 19,500 square miles. Seven of the monitoring sites were sampled by the Iowa Department of Natural Resources, three sites by the Minnesota Pollution Control Agency, three sites by the University of Iowa Institute for Hydraulic Research, and four sites by the U.S. Geological Survey. Water-quality analyses typically consisted of nitrate, ammonia, total nitrogen, and total phosphorus, with limited analyses available for organic nitrogen, dissolved phosphorus, dissolved orthophosphate, and water-soluble pesticides. Long-term historical nutrient and pesticide data were not available for the Wapsipinicon River Basin.

Median concentrations for total nitrogen ranged from 4.6 to 9.4 milligrams per liter, and maximum concentrations of total nitrogen ranged from 4.6 to 31 milligrams per liter. The majority of nitrogen transported in surface waters of the Eastern Iowa Basins study unit is in the form of nitrate (nitrogen). Median concentrations of total phosphorus ranged from less than 0.10 to 0.66 milligram per liter, and maximum concentrations of total phosphorus ranged from less than 0.10 to 5.4 milligrams per liter.

Nitrate varied seasonally. Median concentrations of nitrate were largest during the spring and the winter (6.0 to 7.0 milligrams per liter) compared to the summer and fall (2.0 to 4.0 milligrams per liter). Concentrations of nitrate greater than 10 milligrams per liter typically occurred during spring runoff. Median ammonia concentrations generally were highest during the winter (approximately 0.3–0.5 milligram per liter) compared to the spring and summer when ammonia concentrations were often close to the detection limit (0.01 milligram per liter). In general, the median concentrations of total phosphorus varied less than 0.1 milligram per liter between seasons.

The statistical analysis of the nutrient data typically indicated a strong positive correlation of nitrate with streamflow. Total phosphorus concentrations with streamflow showed greater variability than nitrate, perhaps reflecting the greater potential of transport of phosphorus on sediment rather than in the dissolved phase as with nitrate. Ammonia and ammonia plus organic nitrogen showed no correlation with streamflow or a weak positive correlation. Seasonal variations and the relations of nutrients and pesticides to streamflow generally corresponded with nonpoint-source loadings, although possible point sources for nutrients were indicated by the data at selected monitoring sites. Statistical trend tests for concentrations and loads were computed for nitrate, ammonia, and total phosphorus. Trend analysis indicated decreases for ammonia and total phosphorus concentrations at several sites and increases for nitrate concentrations at other sites in the study unit.

Long-term pesticide data are lacking in the study unit. Atrazine was the most commonly detected pesticide. Maximum concentrations of pesticides usually occurred after spring runoff. Large streamflows during the late summer do not have pesticide concentrations as large as do similar streamflows during the spring that occur soon after the application of pesticides.

## INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began implementation of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the current water-quality conditions and trends of the Nation's water resources and to link assessment with an understanding of the natural and human factors that affect the quality of water (Gilliom and others, 1995). Through a multidisciplinary approach encompassing the sampling and analysis of water, sediment, and aquatic ecology, the program provides a nationwide assessment to aid research, water management, and policy.

Study-unit investigations and national synthesis of information are the major design features of the NAWQA Program that allow water-quality information collected at local and regional scales to be integrated into a nationwide description of water quality. Major activities of the NAWQA Program take place within a set of hydrologic systems called study units. Study units comprise diverse hydrologic systems of river basins, aquifers, or both. The 59 study units that have been identified (see cover of this report) include parts of most of the Nation's major river basins and account for approximately 60 to 70 percent of the Nation's water use and population served by public water supplies (Leahy and Wilber, 1991). The study units vary in size from less than 1,000 to more than 60,000 mi<sup>2</sup>. The Eastern Iowa Basins (EIWA) study unit is one of 15 NAWQA study units that were selected to begin assessment in 1994. Assessment within the EIWA study unit will serve the national NAWQA goals in three respects: (1) By providing a regional description and analysis of the quality of water resources in eastern Iowa and southern Minnesota, (2) by examining the vulnerability of

the water resources to natural and human factors, and (3) by providing consistent and compatible data for use in a national synthesis of information that can be used to interpret results from the many study units on a national scale. One component of the assessment process involves an analysis of historical water-quality data for surface water collected in the EIWA study unit during 1970–95. These water-quality data can provide insight into historical trends and aid in the design of NAWQA studies.

In Iowa, nutrients and pesticides are water-quality topics of concern (Goolsby and others, 1991; Goolsby and Battaglin, 1993; Kalkhoff, 1993; Iowa Department of Natural Resources, 1994a; Hallberg and others, 1996). Considerable concern in recent years has been expressed over health effects of nitrate and pesticides in drinking water (Neill, 1989; Richards and others, 1995). High levels of nitrite and nitrate have been traced to infantile methemoglobinemia (whereby the blood loses its ability to transport oxygen) and are suspected of causing the formation of carcinogenic nitrosamines and nitrosamides (Neill, 1989). Nitrogen and phosphorus compounds can occur naturally in ambient stream water but are normally at low concentrations. Concentrations of nitrogen and phosphorus in stream water can be increased by the discharge from wastewater-treatment facilities, fertilizer runoff, livestock production, soil erosion, and other sources (Hem, 1985). Increased concentrations of nitrogen and phosphorus can promote the growth of algae, which eventually die and decompose, depleting the water column of dissolved oxygen (known as hypoxia), which, in turn, may kill off fish and other aquatic life. In nutrient-poor freshwater, inorganic phosphate is often the factor limiting the growth of aquatic plants and algae. However, nitrate as nitrogen tends to become limiting when phosphate is plentiful (Allen, 1995, p. 89). Large nitrogen loads resulting from fertilizer input to the Mississippi River Basin may be a cause of concern for water quality in the Gulf of Mexico (Justic and others, 1993; Rabalais and others, 1996).

Common herbicides in use in Iowa, such as atrazine and alachlor, are potential carcinogens and have Maximum Contaminant Levels (MCLs) established by the U.S. Environmental Protection Agency (USEPA) for drinking water (U.S. Environmental Protection Agency, 1986). The USEPA lists other

chemicals that have Health Advisory Levels (HALs) for drinking water or have recommended ambient water-quality criteria for the protection of aquatic organisms (Nowell and Resek, 1994). Several recent studies have raised additional concerns about potential effects of manmade chemicals in surface water on the endocrine systems of aquatic and terrestrial organisms (Colborn and Clement, 1992; Colborn and others, 1993; Goodbred and others, 1997).

Information on water-quality conditions is necessary for water-resource management and planning purposes. Specific water-quality issues of primary concern in the EIWA study unit include degradation of aquatic ecosystems, soil erosion, and increased concentrations of nutrients and synthetic organic compounds (including pesticides) (Kalkhoff, 1994). These issues are consistent with the national objectives of the NAWQA Program described previously.

## Purpose and Scope

The purposes of this report are (1) to compile and statistically summarize available data for surface water concerning nutrients and pesticides in the EIWA study unit; and (2) to describe, analyze, and assess the selected nutrient and pesticide data for possible temporal or spatial patterns. Water-quality data from seven surface-water-quality monitoring sites operated by the Iowa Department of Natural Resources (IDNR), three sites operated by the Minnesota Pollution Control Agency (MPCA), three sites operated by the University of Iowa Institute of Hydraulic Research (UIIHR), and four sites operated by the USGS were analyzed to determine concentrations and possible trends.

## Acknowledgments

The authors acknowledge agencies and individuals that have collected and compiled data used in this report, which include the Iowa Department of Natural Resources, the University of Iowa Hygienic Laboratory (Iowa City), the Iowa State Department of Health, the Minnesota Pollution Control Agency, and the U.S. Army Corps of Engineers.

## DESCRIPTION OF THE EASTERN IOWA BASINS

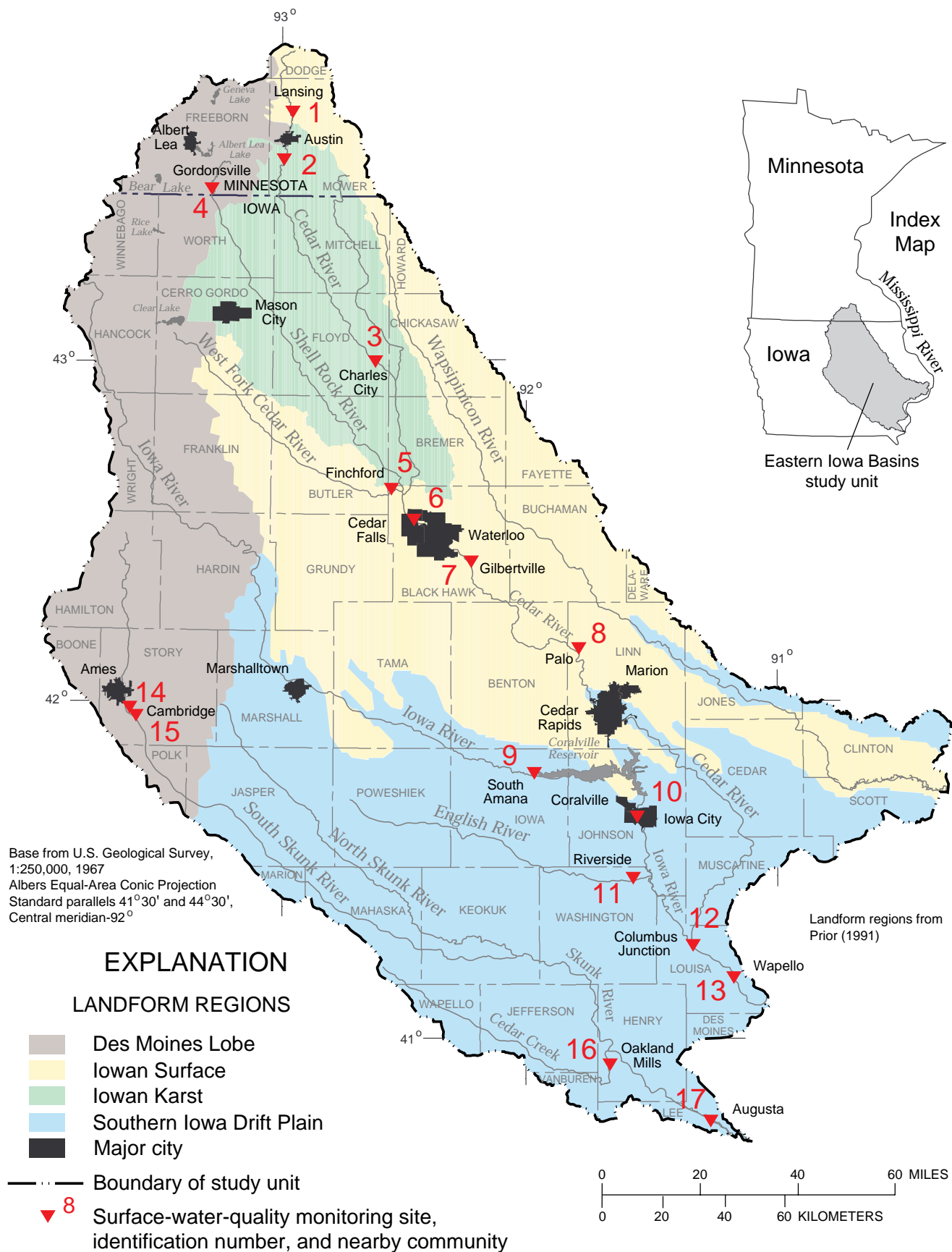
The EIWA study unit encompasses the Wapsipinicon, Cedar, Iowa, and Skunk River Basins, which cover about 19,500 mi<sup>2</sup> of Iowa and south-eastern Minnesota (fig. 1). The four major rivers have their headwaters in the northwestern part of the study unit, flow southeastward, and discharge to the Mississippi River.

## Geomorphology

The EIWA study unit is divided into three major landform regions (Des Moines Lobe, Iowan Surface, and Southern Iowa Drift Plain) (Prior, 1991) and one subregion (Iowan Karst, a subregion of the Iowan Surface) on the basis of distinct spatial differences in topography, geology, soils, and vegetation (fig. 1). These regions also broadly coincide with ecoregions and subcoregions of Iowa (Griffith and others, 1994).

The Des Moines Lobe, in the western part of the study unit, is one of the youngest landforms in Iowa and is characterized by low local relief (50–100 ft). The Des Moines Lobe was formed approximately 12,000 to 14,000 years ago (Wisconsinan age) during the last glaciation in Iowa and has been only slightly altered since that time (Prior, 1991). The topography consists of predominantly flat and slightly rolling land broken by curved bands of “knob and kettle” terrain (Buchmiller and others, 1985). Originally, ponds and wetlands from poor drainage were characteristic of the Des Moines Lobe. Extensive ditching and tiling of fields during 1900–20 have increased the surface drainage in this area. The potential natural vegetation is bluestem prairie (Griffith and others, 1994), although corn and soybean production presently dominates. Stream development is poor with many small, low-gradient streams that drain into relatively few large rivers. Surficial material consists of loamy till that has an average thickness of approximately 100 ft and alluvium in association with large streams. Surficial loess is absent.

The Iowan Surface is characterized by gently rolling topography with long slopes and low local relief (50–100 ft). Drainage is well developed, although streams generally have slight gradients. Surficial material consists of pre-Illinoian-age (500,000–700,000 years old) loamy till covered by



**Figure 1.** Location of the Eastern Iowa Basins study unit, landform regions, and selected surface-water-quality monitoring sites.

a thin veneer of windblown loess on the ridges and alluvium near the streams (Prior, 1991). Potential natural vegetation is bluestem prairie and oak-hickory forest, although corn and soybean production presently dominates (Prior, 1991; Griffith and others, 1994).

The Iowan Karst is a subregion of the Iowan Surface where dissolution of soluble limestone and dolomite under a thin or nonexistent cover of glacial drift has caused localized collapse of the land surface that resulted in a karst topography with numerous sinkholes. The surface drainage is well developed, although local infiltration to bedrock units is common. This area is extensively used for agriculture, and some fields are drained through agricultural drainage wells, which are a form of gravity-operated injection well. Field tile lines are typically connected to these drainage wells. The drainage wells can provide a conduit for surface runoff and field drainage to the underlying bedrock aquifer. Floyd County has the largest number of registered agricultural drainage wells in the EIWA study unit (Libra and others, 1996). In the EIWA study unit, sinkholes are natural features in the Iowan Karst that can affect ground-water quality in a manner similar to the agricultural drainage wells.

The Southern Iowa Drift Plain is characterized by steeply rolling terrain with moderate local relief (100–300 ft) separated by flat, tabular divides. Surficial material consists of pre-Illinoian glacial deposits mantled by loess. Soils on the lower slopes commonly are derived from till, whereas soils on the higher slopes and upland flats are derived from loess. Alluvium is present in association with streams that form a well-developed drainage pattern. Potential natural vegetation is bluestem prairie and oak-hickory forest (Griffith and others, 1994), although corn and soybean production presently predominates.

## Climate

The climate in the EIWA study unit is continental, with large differences in seasonal temperatures that result in well-defined winter and summer seasons. Primary controlling factors that affect the climate in the EIWA study unit are warm, moist air from the Gulf of Mexico and surges of cold, dry air from Canada, which predominate in the summer and winter, respectively (U.S. Department of Commerce, 1959).

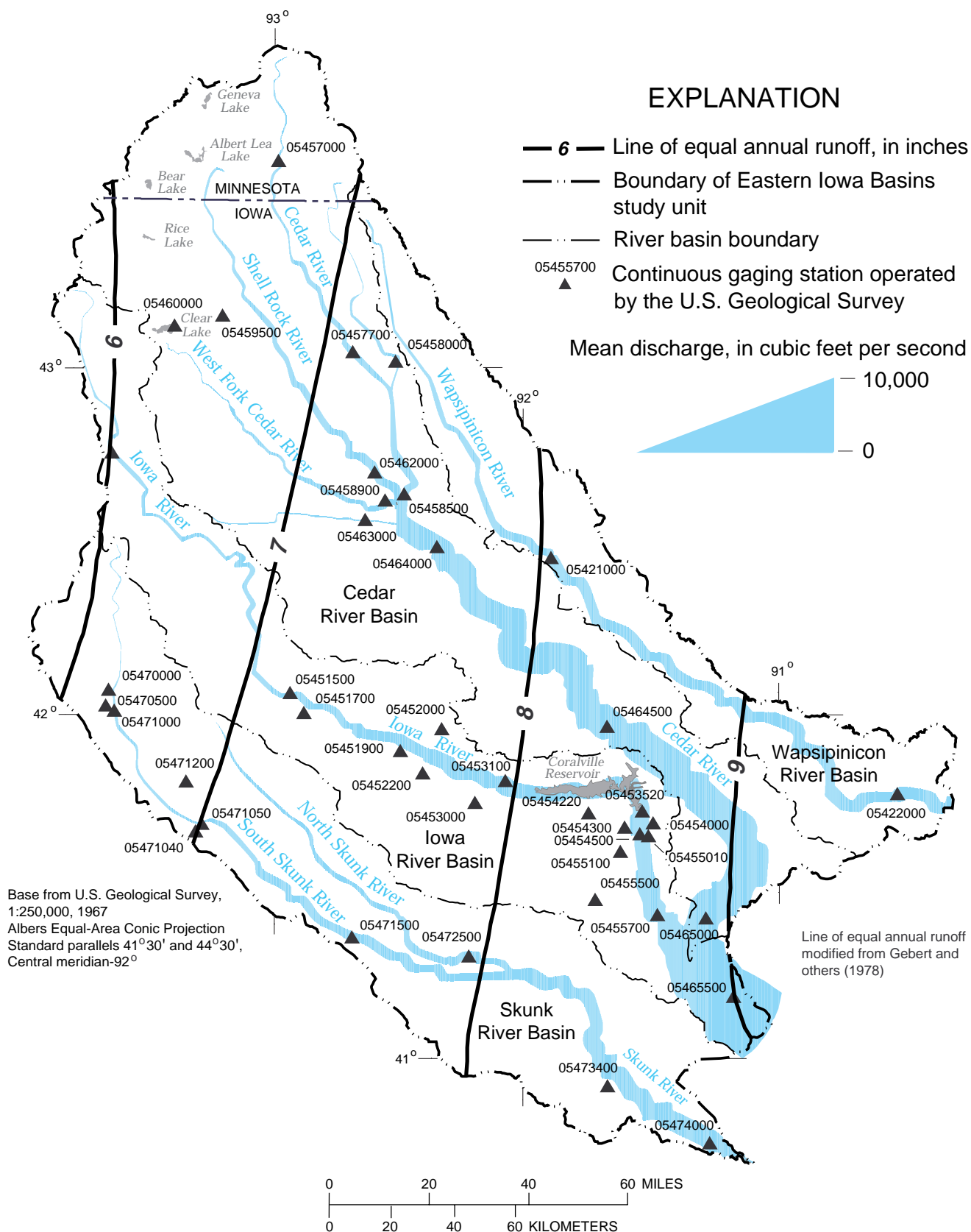
The mean annual temperature for the EIWA study unit is 47°F with average temperatures ranging from 71°F during the warmest months (June, July,

August) to 20°F during December, January, and February (U.S. Department of Commerce, 1959). The growing season, which is approximately 127 days, is characterized by average temperatures that vary from 66°F in the southern part of the EIWA study unit to 60°F in the northern part.

Precipitation occurs mostly as rain from air that moves northward from the Gulf of Mexico. This precipitation is mainly associated with thunderstorms that occur from April through September, during which time the study unit receives approximately 70 percent of its annual rainfall (U.S. Department of Commerce, 1959). Peak precipitation occurs in June when crop-moisture demands are at their greatest and diminishes sharply during the fall harvesting season. Precipitation during the cooler months of the year generally is of long duration and of moderate or low intensity, whereas precipitation during the late spring and summer tends to be of shorter duration and of higher intensity. Snow during the colder winter months can remain on the ground until spring. The mean annual precipitation ranges from 31 inches in the northernmost part of the study unit to 38 inches in the southeastern part (U.S. Department of Commerce, 1959).

## Streamflow

The Wapsipinicon, Cedar, Iowa, and Skunk Rivers flow from northwest to southeast across the study unit toward the Mississippi River at the eastern border of Iowa (figs. 1 and 2). The Wapsipinicon River originates in southeastern Minnesota and is about 225 mi long. The Wapsipinicon River Basin averages about 10 mi wide with a drainage area of 2,540 mi<sup>2</sup>. The Cedar River originates in southern Minnesota and forms the largest basin in the study unit. The Cedar River Basin ranges from 20 to 60 mi wide. The Cedar River joins the Iowa River about 30 mi upstream from the confluence of the Iowa and Mississippi Rivers. The headwaters for the Iowa River are in north-central Iowa. The Iowa River Basin averages 20 mi wide. The Iowa and Cedar River Basins combine to cover 12,640 mi<sup>2</sup>, more than 90 percent of which is in Iowa. The Skunk River originates in central Iowa, has a drainage basin that is about 24 mi wide, and drains approximately 4,350 mi<sup>2</sup>. Eash (1993) has described channel and drainage-basin characteristics for many streams in the EIWA study unit.



**Figure 2.** Mean annual streamflow (water years 1970–95), mean annual runoff (water years 1951–80), and location of continuous streamflow-gaging stations in the Eastern Iowa Basins study unit.

Overland flow (direct surface runoff) and ground-water discharge are the major sources of streamflow. Another source of flow to streams is interflow. Interflow is that part of the subsurface flow that moves at shallow depths and reaches the surface channels in a relatively short period of time and, therefore, is commonly considered part of overland flow. During a storm period, interflow is commonly characterized by slowly increasing up to the end of the storm period, followed by a gradual recession (Viessman and others, 1989). Field tile drains can enhance the subsurface drainage component of flow to streams. In the study unit, the mean annual runoff (overland flow, ground-water discharge, and interflow) to streams (water years 1951–80) averages about 25 percent of the annual precipitation and increases from less than 6 inches in the western part of the study unit to more than 9 inches in the southeastern part (fig. 2). Figure 2 also illustrates the mean annual streamflow (or surface-water discharge) of major streams (water years 1970–95) in the EIWA study unit. Total mean annual streamflow from the study unit (based on the entire period of record available) averages about 9.2 million acre-ft (Kalkhoff, 1994). The mean annual streamflow from the Wapsipinicon River Basin, the combined Iowa and Cedar River Basins, and the Skunk River Basin averages about 1.1, 6.3, and 1.8 million acre-ft, respectively. Statistical summaries of historical streamflow data for approximately 42 streamflow-gaging stations in the EIWA study unit have been compiled by Fischer and Eash (1998).

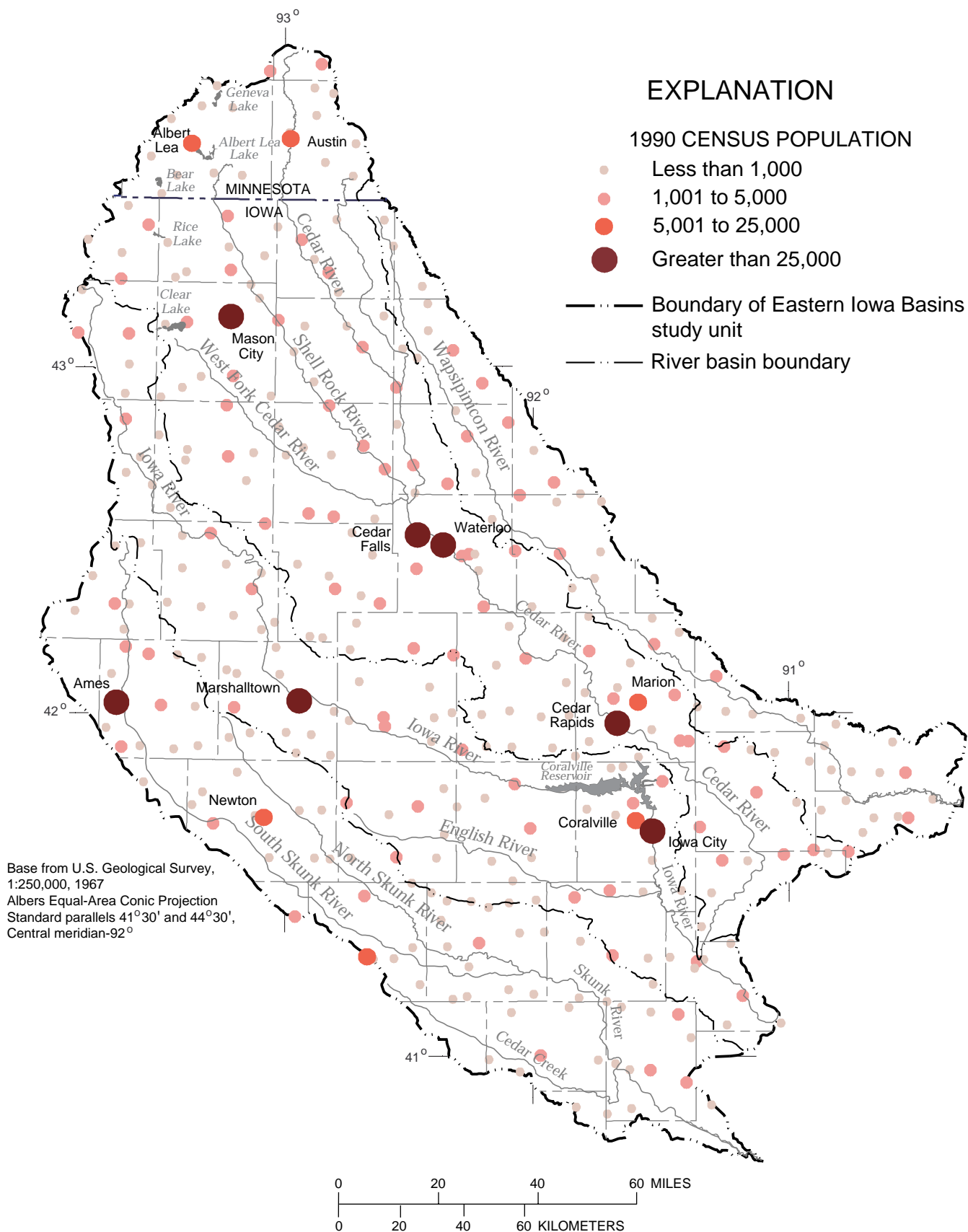
Flooding often occurs as a result of spring melting of snowpack combined with rainfall or thunderstorm activity. Droughts can result from the shift of the normal storm track by high-pressure conditions, a block or decrease in moist air flows, or lack of thunderstorm development. Soenksen and Eash (1991) describe floods and droughts that have affected streamflow in the EIWA study unit. The major floods of 1982 in the EIWA study unit were the result of thunderstorms that began in May and continued through mid-July. Water year 1993 (October 1992 through September 1993) was the wettest in 121 years of record (Southard and others, 1994). The record-breaking precipitation in Iowa during the summer of 1993 resulted in large floods in the EIWA study unit. The drought of 1974–79 was statewide and especially affected the northern half of the EIWA study unit. A drought affecting the western and central part of Iowa occurred during 1979–82 and affected mainly the

southwestern parts of the study unit. The 1988–89 drought was statewide, with high temperatures and near-record minimum precipitation, and affected all of the EIWA study unit (Soenksen and Eash, 1991).

## Population, Land Use, and Water Use

Total population in the EIWA study unit was approximately 1,169,000 in 1990 (U.S. Department of Commerce, 1994)—88 percent in Iowa and 12 percent in Minnesota. Thirty-nine percent of the people were located in 12 principal communities that have populations greater than 10,000. Principal communities are interspersed among small, rural communities and farms (fig. 3). Generally, the population of the principal communities in Iowa from 1980 to 1990 has been relatively stable (table 1). Five of the 12 cities with populations greater than 10,000 are located in the Cedar River Basin. In 1990, population for the entire Cedar River Basin was approximately 553,000, representing 47 percent of the total population within the EIWA study unit. The Iowa River Basin had the next largest population with approximately 231,000 people. The 1990 population for the Skunk and Wapsipinicon River Basins was about 210,000 and 175,000 respectively.

Agriculture accounts for 92.9 percent of the land use in the study unit. Other land uses are forests (4.0 percent), urban (1.8 percent), and other purposes (1.3 percent). Industries, university programs, and research in the largest cities (Cedar Rapids, Waterloo/Cedar Falls, and Iowa City/Coralville) contribute significantly to the agricultural economy. The principal crops are corn, soybeans, oats, hay, and pasture on unirrigated land. Approximately 3.95 million head of cattle were reported in Iowa in December 1995 (Sands and Holden, 1996). Hog production ranked first in the United States—14.4 million head in December 1995 (Sands and Holden, 1996). Numerous hog-production facilities began operation in the 1990's in the study unit. Figure 4 shows the location of permitted livestock facilities in the EIWA study unit, and the majority of these livestock facilities are for hog production. Confinement feeding operations must be permitted by the Iowa Department of Natural Resources before construction if the facility is designed for an animal weight capacity greater than 400,000 pound bovine or 200,000 pounds for other animal species (Iowa Department of Natural Resources, 1998a).



**Figure 3.** Population of communities in the Eastern Iowa Basins study unit, 1990.

The potential negative effects of these hog-production facilities on surface-water quality may be of concern. In particular, the upper parts of the Iowa River and Skunk River Basins have had more than double the number of hog facilities permitted during pre-1993 when compared to post-1993.

Water use in the EIWA study unit totaled about 418 Mgal/d in 1994, of which approximately 52 percent was surface water and 48 percent was ground water. The major water use in the study unit was surface water used as cooling water in power-generating plants (179 Mgal/d). Additionally, approximately 272 Mgal/d of surface water is used instream to produce 2.1 gigawatt-hours of electricity in the study unit (E.E. Fischer and L.C. Trotta, U.S. Geological Survey, written commun., 1994). Approximately 6 Mgal/d of surface water is used in the study unit to supply about 6 percent of the public water supply.

**Table 1.** Population of principal communities in the study unit, 1980 and 1990

[Data from U.S. Department of Commerce, 1994]

Community (fig. 3)	Population	
	1980	1990
Cedar Rapids, Iowa	110,243	108,751
Waterloo, Iowa	75,985	66,467
Iowa City, Iowa	50,508	59,738
Ames, Iowa	45,775	47,198
Cedar Falls, Iowa	26,322	34,298
Mason City, Iowa	30,144	29,040
Marshalltown, Iowa	26,938	25,178
Austin, Minnesota	23,020	21,907
Marion, Iowa	19,474	20,403
Albert Lea, Minnesota	19,200	18,310
Newton, Iowa	15,292	14,789
Coralville, Iowa	7,687	10,347

## METHODS OF INVESTIGATION

Analysis of historical surface-water-quality data in the EIWA study unit often was complicated by the fact that many data-collection programs had a limited spatial or temporal extent and often were confined to a small area (for example, a single municipal site or county). Data-collection programs typically focused on a suspected source of pollution or were operated for only a year or two. These data are important for providing information on local water quality, but often may not represent typical conditions throughout

a basin. Most long-term surface-water-quality information in Iowa is provided by the monitoring and assessment programs of the IDNR and supporting agencies. In addition, the USGS National Stream-Quality Accounting Network (NASQAN) provided monitoring data on the Cedar, Iowa, and Skunk Rivers. Nutrient data were available at all of the monitoring sites selected for these analyses. However, the three NASQAN sites (sites 6, 13, 17; fig. 1) were the only continuous, long-term (more than 5 years) monitoring sites in the EIWA study unit where pesticide data have been collected. The USGS monitoring site on the Cedar River at Gilbertville, Iowa (site 7; fig. 1), had pesticide data for 1984–87 and also was included in the pesticide data analysis, even though the data were short term (less than 5 years) because of the scarcity of pesticide data in the EIWA study unit.

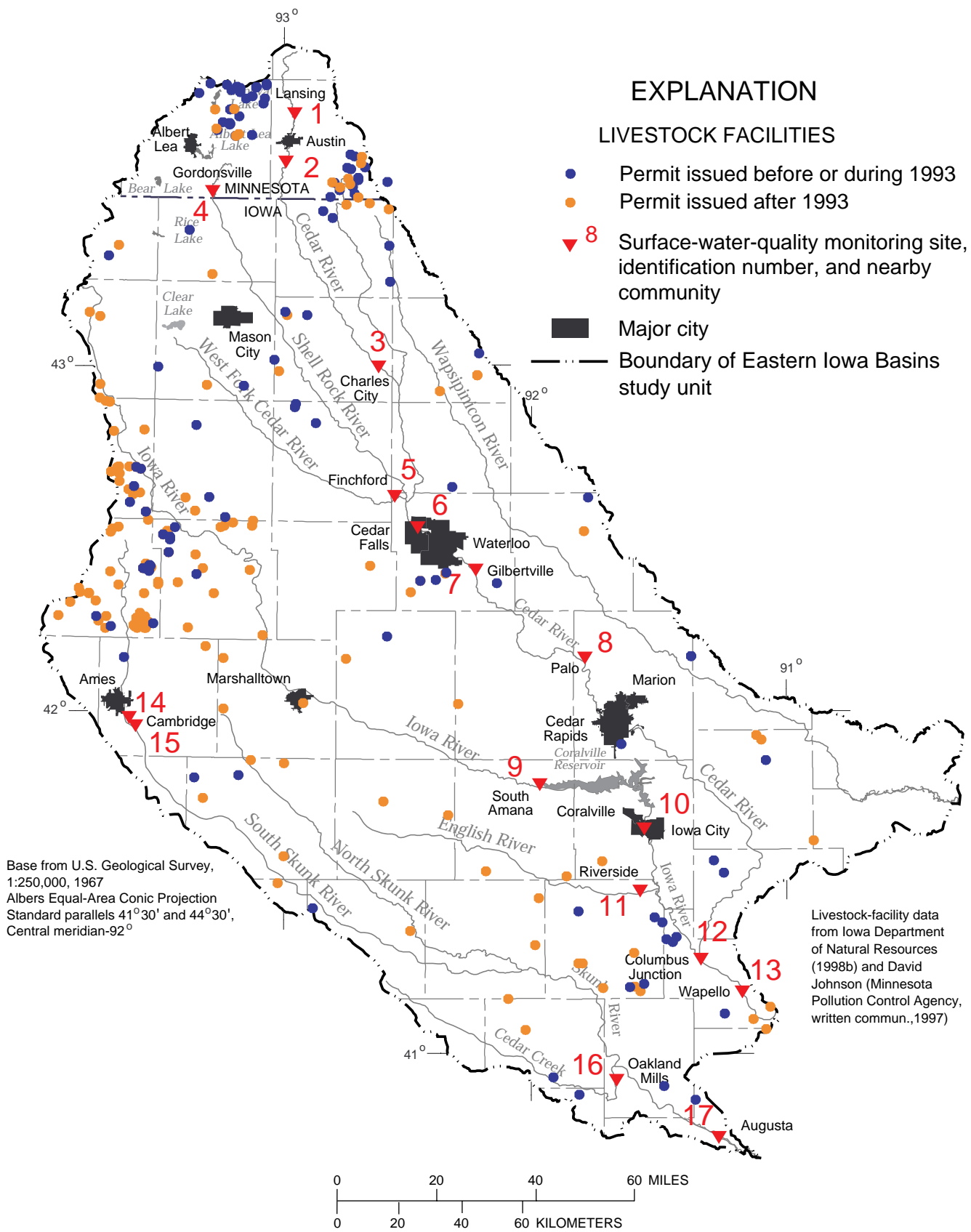
The data and analyses in this report were not intended to provide an exhaustive assessment of past conditions. Rather, data sets were selected from sites with long-term water-quality monitoring records that would indicate general patterns and possible trends in the study unit. Therefore, statistical methods that emphasized broad patterns, such as boxplots and smoothing techniques, were used for much of the data analysis.

## Sources of Nutrient, Pesticide, and Streamflow Data

Three data sets were selected as having the most utility for the regional water-quality assessment: (1) the surface-water-quality monitoring programs of the IDNR and MPCA, (2) the UIIHR monitoring studies of the Iowa and Cedar Rivers, and (3) the four USGS water-quality monitoring sites.

### Iowa Department of Natural Resources and Minnesota Pollution Control Agency

The data set from the IDNR had seven monitoring sites, and the MPCA data set had three monitoring sites that were selected for this report. The Environmental Protection Division of the IDNR and the University of Iowa Hygienic Laboratory (UHL) operate a network of surface-water-quality monitoring sites in the EIWA study unit on the Wapsipinicon, Cedar, Iowa, and Skunk Rivers and other major tributaries. The MPCA operates water-quality monitoring sites in the upstream part of the Cedar River Basin. Several of the monitoring sites have been operated



**Figure 4.** Location of permitted livestock facilities in the Eastern Iowa Basins study unit.

since the 1970's and have been sampled either monthly or quarterly. Pesticide monitoring is not conducted as part of the IDNR or MPCA fixed-site water-quality monitoring network.

The IDNR statewide monitoring provides basic information on water-quality trends for prospective users of surface water. Specific objectives of the program are to determine water quality during changing conditions, sources of water-quality degradation, and effects of pollution, and to compile data needed to support enforcement and pollution abatement. Data are published in biennial reports, also called Section 305(b) reports, which are transmitted by the IDNR to the USEPA. Reports have been published since 1975 and generally provide a statewide overview rather than a detailed site-specific discussion of water quality. Water-quality data are available in the USEPA's STORage and RETrieval (STORET) data base. The water-quality period of record for the seven IDNR sites selected for this study ranged from 6 to 18 years (table 2). The South Skunk River near Ames (site 14) only had data for 1 year in STORET, and it was later moved to South Skunk River near Cambridge (site 15). The period of record for the three MPCA sites selected ranged from 19 to 24 years.

The IDNR water samples were collected from just beneath the water surface in the center of flow by a grab sample (Iowa Department of Natural Resources, 1994b). Samples were not collected within 72 hours of peak of streamflow (Iowa Department of Natural Resources, 1994b). Samples were analyzed at the UHL. The MPCA monthly samples were collected using a grab sampler at a point in the stream most likely to represent the water quality of the total instantaneous flow (Sandra Bissonnette, Minnesota Pollution Control Agency, written commun., 1998). Water samples were analyzed at the Minnesota Department of Health Laboratory. The MPCA monitoring program has been in existence in some form since 1953 and is administered and implemented by the Monitoring and Data Management Unit of the Water-Quality Division.

Streamflow data for the IDNR and MPCA sites were from the STORET data base, if available. However, streamflow data for the Cedar River near Austin, Minnesota, monitoring site (site 2, fig. 1) were not in STORET, and these data were obtained from the USGS office in Mounds View, Minnesota, for the USGS streamflow-gaging station at Cedar River near Austin, Minnesota (05457000, fig. 2).

## University of Iowa Institute of Hydraulic Research

The UIIHR has conducted two long-term studies within the EIWA study unit—the Coralville Reservoir Water-Quality Study conducted from 1964 through the present and the Cedar River Baseline Ecological Study conducted from 1974 to the present. Similar methods were used and similar constituents were analyzed during both studies. The Coralville Reservoir Water-Quality Study was begun in 1964 to investigate the effects of a flood-control reservoir on the water quality and limnology of the Iowa River. The study was conducted by the UIIHR in cooperation with the U.S. Army Corps of Engineers (USCOE). Water-quality samples for the Coralville study were collected at monitoring sites located upstream from Coralville Reservoir, within Coralville Reservoir, and downstream from Coralville Reservoir. Data selected from STORET for the EIWA study unit were limited to the upstream monitoring site (site 9 near South Amana) and the downstream site (site 10 at Iowa City). These data were selected to represent ambient conditions in the Iowa River upstream and downstream from the Coralville Reservoir. Water-quality samples were collected from the Iowa City site weekly or biweekly, although data collection was occasionally interrupted at that site (table 2). Determinations of pH, water temperature, dissolved oxygen, and alkalinity were made onsite at the time of sample collection. Water samples were collected throughout the year utilizing a Kemmerer water sampler. Laboratory work was performed in the University of Iowa Water Treatment Plant (Iowa City) or the UHL. Water samples were analyzed by standard USEPA procedures (U.S. Environmental Protection Agency, 1972, 1979; American Public Health Association and others, 1976).

Streamflow data for the Iowa River at Marengo streamflow-gaging station (05453100, fig. 2) were obtained from the USGS Automated Data Processing System (ADAPS) data base and used in conjunction with the South Amana (site 9, fig. 1) water-quality data because it was the closest streamflow-gaging station to the monitoring site (located approximately 2 mi upstream from site 9). There are no major tributaries that contribute to the Iowa River streamflow between the Marengo streamflow-gaging station and the monitoring site at South Amana. Daily mean streamflow data for the monitoring site at Iowa City (site 10, fig. 1) were obtained from the USGS ADAPS data base for the streamflow-gaging station (05454500, fig. 2) at that site.

**Table 2.** Period of record and number of samples analyzed for selected water-quality constituents at monitoring sites in the Eastern Iowa Basins study unit

[Period of record given by month and year; for example, 07/75–05/79. The number of samples analyzed is in parentheses. \*, sporadic data, either no data available or less than 20 analyses for period of record; ND, no data]

Site name and number (fig. 1)	Nitrogen, nitrite plus nitrate	Nitrogen, ammonia	Organic nitrogen or organic nitrogen plus ammonia nitrogen	Nitrogen, total (calculated)	Phosphorus, total	Phosphorus, dissolved	Ortho-phosphate, dissolved	Alachlor	Atrazine	Cyanazine	Metolachlor	Metribuzin
<b>Iowa Department of Natural Resources</b>												
Cedar River near Charles City (site 3)	03/78–12/96 (210)	03/78–09/79, 12/80–12/95 (197)	03/78–12/95 (208)	03/78–12/95 (208)	03/78–12/95 (198)	ND	03/78–09/79, 10/86–12/95 (133)	ND	ND	ND	ND	ND
West Fork Cedar River near Finchford (site 5)	10/86–12/95 (112)	10/86–12/95 (112)	10/86–12/95 (113)	10/86–12/95 (112)	10/87–12/95 (101)	ND	10/86–12/95 (112)	ND	ND	ND	ND	ND
English River near Riverside (site 11)	10/86–12/95 (106)	10/86–12/95 (106)	10/96–12/95 (106)	10/86–12/95 (106)	10/87–12/95 (95)	ND	10/86–12/95 (106)	ND	ND	ND	ND	ND
Iowa River at Columbus Junction (site 12)	05/88–12/95 (93)	05/88–12/95 (93)	05/88–12/95 (93)	05/88–12/95 (93)	05/88–12/95 (93)	ND	05/88–12/95 (93)	ND	ND	ND	ND	ND
South Skunk River near Ames (site 14)	03/70–12/70 (41)	03/70–12/70 (43)	ND	ND	02/70–12/70 (45)	ND	ND	ND	ND	ND	ND	ND
South Skunk River near Cambridge (site 15)	07/89–12/95 (78)	07/89–12/95 (78)	07/89–12/95 (77)	07/89–12/95 (77)	07/89–12/95 (77)	ND	07/89–12/95 (77)	ND	ND	ND	ND	ND
Cedar Creek near Oakland Mills (site 16)	10/86–12/95 (111)	10/86–12/95 (111)	10/86–12/95 (111)	10/86–12/95 (111)	10/87–12/95 (101)	ND	11/86–12/95 (110)	ND	ND	ND	ND	ND
<b>Minnesota Pollution Control Agency</b>												
Cedar River near Lansing (site 1)	01/70–06/76, 01/81–09/94 (196)	01/70–06/76, 01/81–09/94 (196)	01/70–06/71, 08/73–09/94 (177)	01/70–06/71, 08/73–09/94 (177)	08/70–06/71, 10/80–09/94 (189)	ND	ND	ND	ND	ND	ND	ND
Cedar River near Austin (site 2)	01/70–09/94 (246)	01/70–09/94 (246)	01/70–04/71, 08/73–09/94 (226)	01/70–04/71, 08/73–09/94 (226)	01/70–09/94 (246)	ND	ND	ND	ND	ND	ND	ND
Shell Rock River near Gordonsville (site 4)	01/70–09/94 (245)	01/70–09/94 (245)	01/70–06/71, 08/73–09/94 (226)	01/70–06/71, 08/73–09/94 (226)	01/70–09/94 (246)	ND	ND	ND	ND	ND	ND	ND

**Table 2.** Period of record and number of samples analyzed for selected water-quality constituents at monitoring sites in the Eastern Iowa Basins study unit—Continued

[Period of record given by month and year; for example, 07/75–05/79. The number of samples analyzed is in parentheses. \*, sporadic data, either no data available or less than 20 analyses for period of record; ND, no data]

Site name and number (fig. 1)	Nitrogen, nitrite plus nitrate	Nitrogen, ammonia	Organic nitrogen or organic nitrogen plus ammonia nitrogen	Nitrogen, total (calculated)	Phosphorus, total	Phosphorus, dissolved	Ortho-phosphate, dissolved	Alachlor	Atrazine	Cyanazine	Metolachlor	Metribuzin
<b>University of Iowa Institute of Hydraulics</b>												
Cedar River near Palo (site 8)	04/71–09/95 (550)	04/71–09/95 (546)	ND	ND	05/71–04/73, 01/77–09/95 (477)	09/82–04/84 (31)	04/71–10/78, 09/79–08/82, 01/84–09/95 (509)	ND	ND	ND	ND	ND
Iowa River near South Amana (site 9)	02/77–09/95 (500)	02/77–09/95 (527)	05/92–06/94 (49)	05/92–09/95 (49)	ND	12/79–10/81 (102)	02/77–11/79, 11/83–09/94 (91)	ND	ND	ND	ND	ND
Iowa River at Iowa City (site 10)	01/70–12/79,* 01/79–09/95 (563)	01/70–12/79,* 01/79–09/95 (598)	01/70–08/79,* 05/92–03/95* (88)	01/70–08/79,* 05/92–03/95* (88)	01/70–08/79* (44)	01/70–08/76,* 12/79–10/81 (128)	01/70–04/70, 04/72–06/72, 01/73–04/73, 08/73–03/74, 09/76–11/79, 09/83–09/84 (141)	ND	ND	ND	ND	ND
<b>U. S. Geological Survey</b>												
Cedar River at Cedar Falls (site 6)	07/75–05/79, 05/84–08/95 (129)	07/75–05/79, 05/84–08/95 (114)	07/75–05/79, 05/84–08/95 (112)	07/75–05/79, 05/84–08/95 (113)	07/75–09/79, 05/84–08/95 (114)	05/84–08/95 (70)	05/84–08/95 (69)	05/84–09/85, 05/87–08/95 (68)	05/84–09/85, 05/87–08/95 (68)	05/84–09/85, 05/87–08/95 (68)	05/84–09/85, 05/87–08/95 (68)	05/84–09/85, 05/87–08/95 (55)
Cedar River at Gilbertville (site 7)	07/75–09/81, 05/84–11/85 01/87 (79)	07/75–09/81, 05/84–11/85 01/87 (79)	07/75–09/81, 05/84–11/85, 01/87 (77)	07/75–09/81, 05/84–11/85, 01/87 (77)	07/75–09/81, 05/84–01/87 (79)	05/84–11/85 (18)	05/84–11/85 (21)	05/84–11/85, 01/87 (17)	05/84–11/85, 01/87 (18)	05/84–11/85, 01/87 (17)	05/84–11/85, 01/87 (17)	05/84–11/85, 01/87 (17)
Iowa River at Wapello (site 13)	11/77–08/95 (117)	11/77–08/95 (115)	11/77–08/95 (116)	11/77–08/95 (116)	11/77–08/95 (116)	11/77–08/95 (114)	11/81–08/95 (82)	10/85–08/95 (39)	10/85–08/95 (39)	10/85–08/95 (39)	10/85–08/95 (39)	10/85–08/95 (38)
Skunk River at Augusta (site 17)	11/77–08/95 (123)	11/77–08/95 (117)	11/77–08/95 (113)	11/77–08/95 (113)	11/77–08/95 (115)	11/77–08/95 (115)	11/81–08/95 (83)	05/87–08/95 (39)	05/87–08/95 (39)	05/87–08/95 (39)	05/87–08/95 (39)	05/87–08/95 (38)

The Cedar River Baseline Ecological Study was begun in 1974 to investigate the effects of the operation of the Duane Arnold Energy Center near Palo, Iowa, on the ecology and water quality of the Cedar River. The Duane Arnold Energy Center is a nuclear-fuel electrical-generating plant located about 2.5 mi north-northeast of Palo. The study was conducted by the UIIHR in cooperation with the Duane Arnold Energy Center. Water-quality samples were collected at five separate sites on the Cedar River. The data for monitoring site 8 (fig. 1), located upstream from the generating plant, were selected for use in the EIWA study unit because water quality would not be affected by the generating plant. Data were retrieved from the STORET data set. The data set includes nutrient data from 1971–95 (site 8, table 2). Streamflow data for the Cedar Rapids streamflow-gaging station (05464500, fig. 2) were obtained from the USGS ADAPS data base and used in conjunction with the Palo (site 8, fig. 1) water-quality data, as it was the closest streamflow-gaging station to the monitoring site. The Cedar Rapids streamflow-gaging station is approximately 10–12 mi downstream of the Palo monitoring site. There are no large tributaries that flow into the Cedar River between Palo and Cedar Rapids.

### **U.S. Geological Survey**

The USGS has collected and analyzed surface-water samples as part of various programs. The water-quality data are stored in the USGS National Water Information System (NWIS) data base. The majority of the data have been published in a series of annual reports, “Water Resources Data, Iowa,” compiled by the USGS in Iowa City, Iowa. The USGS water-quality data used in this report were retrieved from the NWIS data base. Data retrieved for this report include nutrient and pesticide data from three USGS sites operated as part of the NASQAN program (sites 6, 13, and 17) and one USGS site operated as part of the USGS cooperative program (site 7). The NASQAN program was begun in 1973 to provide nationally comparable information on water quality. NASQAN stations typically are sampled frequently enough to characterize variations in chemical concentrations that occur during a year, particularly variation that occurs between low and high flows during different seasons.

The water-quality period of record for the USGS sites ranged from 10 to 18 years for nutrient data and 3 to 10 years for pesticide data (table 2). The

sample-collection methods and laboratory procedures for the four USGS sites were similar. Water samples for nutrients were obtained by collecting depth-integrated subsamples at equally spaced vertical sections across the stream (Ward and Harr, 1990). Pesticide samples were collected in precleaned glass bottles from the centroid of streamflow. All samples were preserved by chilling on ice. Pesticide samples were sent to the University of Iowa Hygienic Laboratory, and other samples were shipped to the USGS National Water-Quality Laboratory by air express. Streamflow data for the USGS monitoring sites were from the USGS ADAPS or NWIS data bases.

### **Data Compilation and Statistical Methods**

The data sets contained various combinations of nutrient data; the USGS data also contained pesticide data. Quality-control replicate samples were deleted from the data sets to avoid biasing the number of samples in the data set. The STORET data were examined for erroneous values by comparison with published data when possible and corrected according to the published data. No attempt was made to correct or delete outlier values in the data sets if published records were not available. However, in three cases, concentrations that were apparent typographical errors were deleted from the data sets. The Statistical Analysis System (SAS) software package was used to identify and compile nutrient data for statistical analysis from all three data sets.

The majority of the nutrient and pesticide data within these data sets were reported as dissolved constituents. It is important to distinguish between the terms “dissolved” and “total.” The terms “dissolved” and “total” distinguish between filtered and nonfiltered concentrations, respectively. The dissolved-nutrient and dissolved-pesticide concentrations were used unless total constituent values were the only values available. Total values then were used with the assumption that most of the constituents were in the dissolved phase. Typically, the nitrogen-containing compounds were reported as dissolved concentrations in the data sets, although ammonia concentrations for the IDNR and UHL sites were mostly reported as total (unfiltered) ammonia. All nitrogen-containing compounds described in this report are reported as equivalent amounts of elemental

nitrogen (mg/L as N). The terms “dissolved” or “total” were not used as descriptors for ammonia, organic nitrogen, nitrite plus nitrate, or nitrate when presenting these nitrogen species in the tables or figures in this report; however, they are used in the text when it is necessary to refer to specific types of laboratory analyses. All phosphorus species described in the assessment are reported as equivalent amounts of elemental phosphorus (mg/L as P). The majority of data for phosphorus concentrations were as “total phosphorus,” which refers to all the phosphorus species present. Occasionally, data on dissolved phosphorus and dissolved orthophosphate were present in the data sets. In the cases where dissolved phosphorus and dissolved orthophosphate data were available, the descriptor “dissolved” is retained when discussing these phosphorus compounds in the text and all tables and figures. “Total” or “dissolved” are not used as descriptors for the pesticide compounds in this report.

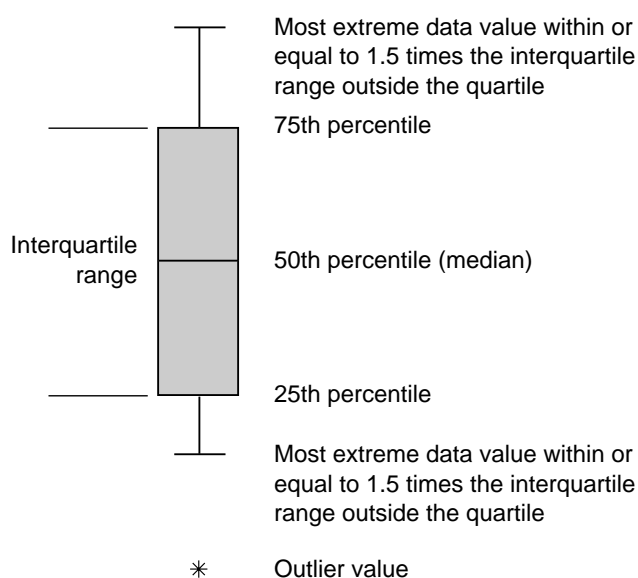
“Total nitrogen” (total N), as used in this report, refers to the summation of all the nitrogen species. Total nitrogen concentrations were obtained by using three different methods. The first method calculated total nitrogen by summing the three nitrogen-species concentrations (if all species were present)—nitrite plus nitrate as nitrogen, organic nitrogen as nitrogen, and ammonia as nitrogen. The second method calculated total nitrogen by summing nitrite plus nitrate as nitrogen and ammonia plus organic nitrogen as nitrogen. The third method used total nitrogen as given by the laboratory if that was the only species reported in the data set. The Palo site (site 8, fig. 2) had only 4 years of data with ammonia nitrogen plus organic nitrogen as nitrogen concentrations, so total nitrogen concentration was not calculated for this site.

There was some variation in the minimum analytical reporting levels [concentrations reported as “less than” (<) a particular value] for the various nutrient species and pesticides in the data sets. In general, the minimum analytical reporting levels for the MPCA organic nitrogen and ammonia data were more variable than the IDNR, UIIHR, and USGS data sets. The MPCA minimum analytical reporting levels for organic nitrogen and ammonia ranged from <0.1 to <0.3 mg/L. The lowest common analytical reporting level for each nutrient and pesticide compound was selected in the data sets. Concentrations reported as “less than the reporting level” (for example, <0.1 mg/L) in the data sets were replaced with a

concentration that was one-half of the lowest common analytical reporting level for statistical calculations of the data. For example, if nitrate as nitrogen was reported as <0.1 mg/L in the data set, it would be set to 0.05 mg/L for statistical calculation of the data. The lowest common analytical reporting level selected for nutrients was 0.1 mg/L, for all data sets. The exception was ammonia nitrogen, for which the lower reporting level (0.01 mg/L) available from the USGS data was used. For pesticides, the lowest common analytical level (0.1 mg/L) was selected, with the exception of cyanazine (0.2 mg/L).

Three different measures of nitrate-related species were retrieved from the different data bases: total nitrite plus nitrate, total nitrate, and dissolved nitrite plus nitrate. Data for these three constituents were combined and will be referred to in the figures and tables as “nitrite plus nitrate” and simply as “nitrate” in the text to reduce wordage. This is reasonable because the concentrations of nitrite are small when compared to nitrate concentrations. Typically, nitrate concentrations often are two orders of magnitude greater than the concentration of nitrite in oxygenated water, and the nitrite in surface water typically does not exceed 0.5 mg/L (National Research Council, 1978). At pH values less than 9.3, most of the ammonia dissolved in water is generally ionized ammonium ( $\text{NH}_4^+$ ) (Hem, 1985, p. 126). In this report, “ammonia” is used to refer to both ammonia and ammonium nitrogen ( $\text{NH}_3\text{-N}$  and  $\text{NH}_4\text{-N}$ , respectively).

Nutrient and pesticide data were analyzed using a variety of graphical and statistical methods. The median and variability of data are shown using boxplots (fig. 5). In this plot, a box is drawn from the 25th to the 75th quartile (interquartile range), and the median is shown as a horizontal line in the box. “Whiskers” are drawn from the ends of the box to the most extreme data values within or equal to 1.5 times the interquartile range outside the quartile. Outlier values can be shown above or below the “whiskers” on the boxplot. The univariate procedure of SAS was used to calculate the statistical summaries for the chemical data, such as mean, median, minimum and maximum concentrations, standard error, and percentiles (SAS Institute Inc., 1989). Spearman’s rho is a nonparametric measure of the strength of association between two variables and was used to quantify the relation between concentrations and streamflow (Ott, 1993).



**Figure 5.** Example boxplot showing central tendency and variability of data.

To better visualize nonlinear trends in the concentration and streamflow data, a LOWESS (LOcally WEighted Scatterplot Smoothing) trend line (Cleveland, 1979; Helsel and Hirsch, 1992) was calculated and plotted for each scatterplot presented in this report. The LOWESS trend lines illustrate relations between concentrations and streamflow that are difficult to discern in a simple scatterplot. The LOWESS trend line is computed by fitting a weighted least-squares equation to the concentration and streamflow data (Helsel and Hirsch, 1992, p. 288–291). The “smoothing” used to calculate the LOWESS trend line is a particularly useful technique because no assumptions about linearity of the data are required. The smoothing algorithm uses nearby data points to calculate a “smoothed value” for every data point. Each nearby data point is weighted so that the more distant points affect the smoothed value less than points that are closer. A line then is drawn through the smoothed values. The number of nearby points used to calculate a smoothed value is controlled by the smoothness factor. A smoothness factor of 0.5 was used for all LOWESS trend lines in this report. This means that the closest 50 percent of all the data points were used to calculate each smoothed value.

Time-series constituent concentration plots for nutrients at all the monitoring sites were compared visually and by using a statistical test called the seasonal Kendall tau test to detect trends (Hirsch and others, 1982; Smith and others, 1982). The seasonal

Kendall tau was computed for nitrate, ammonia, and total phosphorus for all monitoring sites for which a complete data set was available. The seasonal Kendall tau trend test can indicate long-term improvement or deterioration in stream quality. The seasonal Kendall tau test is based on the nonparametric Kendall’s tau test (Kendall, 1975), which compares the relative values of all possible pairs of data values in a time series. In the seasonal Kendall tau test, comparisons between data values are restricted to pairs of data values that are from the same time period annually; this period is defined as a “season.” Instantaneous loads were calculated for nitrate, ammonia, and total phosphorus by multiplying the nutrient concentration by the streamflow at the time of the sample. The seasonal Kendall tau tests then were computed for these instantaneous loads.

The seasonal Kendall tau test also was used for testing a null hypothesis of no trend (the constituent concentration and its time of observation are independent). A statistically significant trend is indicated when the null hypothesis obtained from the seasonal Kendall tau test has a probability level (p-value) of 0.05 or less. For example, a p-value of 0.05 means that there is a 5-percent chance of making an error when rejecting the null hypothesis. In this report, p-values less than or equal to 0.05 were considered statistically significant in indicating upward or downward trends in constituent concentrations.

## Spatial and Temporal Records

The majority of the selected monitoring sites with water-quality data were located on the largest rivers in the EIWA study unit—the Cedar, Iowa, and Skunk Rivers (fig. 1). The Wapsipinicon River did not have monthly, long-term (5 years or greater) monitoring data available. Data from several monitoring sites on tributaries also were included. Characteristics of the monitoring sites, such as drainage area, source of streamflow data, sampling agency, and locations, are shown in table 3. The monitoring site number is a sequential number arranged in downstream order. Drainage areas for the monitoring sites range from approximately 180 to 12,500 mi<sup>2</sup>. Water-quality samples generally were collected monthly at all of the monitoring sites. The USGS-NASQAN sites generally had quarterly data. Typically, data on nitrate, ammonia, and total phosphorus concentrations were the most complete for all the data sets throughout the assessment period (table 2).

**Table 3.** Description of selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

Monitoring site number (fig. 1)	Monitoring site name	Approximate drainage area (square miles)	Stream-flow data <sup>1</sup>	Sampling agency <sup>2</sup>	Location and comments
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	250	--	MPCA	County-State Highway 2, 0.5 mile east of Lansing
2	Cedar River near Austin, Minnesota	425	G, S	MPCA	County-State Highway 4, 3 miles south of Austin (station 0545700)
3	Cedar River near Charles City, Iowa	1,080	G, S	IDNR/UHL	About 4 miles southeast of Charles City (station 05457700)
4	Shell Rock River near Gordonsville, Minnesota	180	--	MPCA	County-State Highway 1, 1 mile west of Gordonsville
5	West Fork Cedar River near Finchford, Iowa	846	--	IDNR/UHL	County road T71 near Finchford
6	Cedar River at Cedar Falls, Iowa	4,730	G	USGS	Highway 20 bridge at Cedar Falls (gage is located downstream at Waterloo, station 05464000)
7	Cedar River at Gilbertville, Iowa	5,230	N	USGS	County highway D38 bridge at Gilbertville (station 05464020 discontinued)
8	Cedar River near Palo, Iowa	6,340	E	UIIHR/DAEC	Lewis access, about 6.5 miles north of Palo
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	2,860	E	UIIHR/USCOE	Highway 220 bridge, about 1 mile north of South Amana
10	Iowa River at Iowa City, Iowa	3,270	G	UIIHR	Burlington Street Bridge (station 05454500)
11	English River near Riverside, Iowa	626	E, S	IDNR/UHL	W61 bridge near Riverside
12	Iowa River at Columbus Junction, Iowa	12,300	S	IDNR/UHL	Highway 92 bridge at Columbus Junction
13	Iowa River at Wapello, Iowa	12,500	G	USGS	Highway 99 bridge at Wapello (station 05465500)
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	556	--	IDNR/UHL	Downstream from Ames water-treatment plant
15	South Skunk River near Cambridge, Iowa	585	--	IDNR/UHL	E55 bridge near Cambridge downstream from new Ames water-treatment plant
16	Cedar Creek near Oakland Mills, Iowa	530	G	IDNR/UHL	County highway H46, 3 miles northwest of Oakland Mills (station 05473400)
17	Skunk River at Augusta, Iowa	4,300	G	USGS	Highway 394 at Augusta (station 05474000)

<sup>1</sup>G, streamflow-gaging station at site; S, streamflow data in STORET data base; E, streamflow data estimated from streamflow-gaging station near monitoring site; N, streamflow data in U.S. Geological Survey National Water Information System (NWIS) data base; --, not available.

<sup>2</sup>DAEC, Duane Arnold Energy Center near Palo, Iowa; IDNR, Iowa Department of Natural Resources; MPCA, Minnesota Pollution Control Agency; UHL, University of Iowa Hygienic Laboratory; UIIHR, University of Iowa Institute of Hydraulic Research; USCOE, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey.

## SELECTED NUTRIENTS AND PESTICIDES IN STREAMS

The variety of agencies collecting water-quality data often results in diverse data sets. The various sample-collection protocols, analytical methods, and sampling frequencies can make comparisons between data sets difficult. Water-quality data used in the EIWA study unit have been collected for many specific purposes and programs. State and local regulatory agencies collect data to develop and determine compliance with operating permits and drinking-water regulations. State and Federal natural-resource agencies collect water-quality data to provide information for water managers to make decisions on resource planning and use. Municipalities and industries collect data on the quality and quantity of their wastewater discharges to streams. Universities often collect water data to support basic and applied research. Interpretations between data sets certainly are possible but should be treated with more caution than interpretations within a particular data set.

### Nutrients

Nitrogen species are a water-quality concern primarily because they contribute to aquatic plant growth (in particular algae), eutrophication, and toxicity. Algae generally prefer ammonia over nitrate for growth (Brezonik, 1973, p. 11), but both the reduced species of nitrogen (ammonia and organic nitrogen) and the oxidized species (nitrite and nitrate) can be used as nutrients for algal growth. The excessive growth of algae can promote eutrophication in surface water. Some nitrogen species also are potentially toxic. Freshwater fish are very sensitive to un-ionized ammonia ( $\text{NH}_3$ ), which increases with increasing pH and temperature, and to the total ammonia-nitrogen concentration ( $\text{NH}_4$  as N). At a pH of 9.3 and a temperature of 25°C, about one-half of the ammonia is in the un-ionized form ( $\text{NH}_3$ ) (Hem, 1985, p. 126). Generally, most water analyses only report the total ammonia concentration (the sum of the ammonium ion concentration and the un-ionized or solvated ammonia); the un-ionized ammonia fraction typically is not reported separately. This report does not consider the un-ionized species of ammonia separately. Total ammonia concentrations in surface water

can be of concern, especially during low-flow conditions. Volatilization and loss of ammonia to the atmosphere can be a significant process in streams during the summer months, particularly with increasing pH and temperature. The USEPA has tabulated toxic concentrations of total ammonia-nitrogen ( $\text{NH}_4$  as N) as a function of pH and temperature (U.S. Environmental Protection Agency, 1986). Nitrite and nitrate can be a health concern, particularly for pregnant women and children. Nitrate is converted to nitrite in the digestive tract of warm-blooded animals. The nitrite then interferes with respiration by inhibiting the ability of hemoglobin to transport oxygen. Nitrite concentrations exceeding 1.0 mg/L as nitrogen may be particularly harmful to infants and unborn babies. The USEPA MCL for nitrate in drinking water is 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1986). Wastewater-treatment-plant effluent, manure, and commercial fertilizers are common sources of ammonia, organic nitrogen, nitrite, and nitrate.

Phosphorus, like nitrogen, is an essential nutrient for plant growth, and high concentrations of phosphorus in streams promote aquatic plant growth and eutrophication. To prevent the excessive growth of aquatic plants in streams, the USEPA recommends that total phosphorus concentrations not exceed 0.1 mg/L as P (U.S. Environmental Protection Agency, 1986). Orthophosphate ( $\text{PO}_4^{3-}$ ) is the most stable form of phosphorus in natural water, and forms such as  $\text{H}_3\text{PO}_4$ ,  $\text{H}_2\text{PO}_4^-$ , and  $\text{HPO}_4^{2-}$  are the other common phosphorus-containing compounds (Hem, 1985, p. 126). The majority of the total phosphorus in streams is associated with suspended particles as phosphorus readily adsorbs to soils and sediment. About 95 percent of the phosphorus transported by rivers is adsorbed on sediment (Meybeck, 1982). Dissolved phosphorus in water typically is no more than a few tenths of milligrams per liter (Hem, 1985, p. 126). However, the soluble or dissolved form of phosphorus is the most readily used by algae and other aquatic plants. Most dissolved phosphorus is present as orthophosphate (often called dissolved inorganic phosphorus or dissolved reactive phosphorus); lesser amounts are present as phosphate esters or polyphosphates (often called organic phosphates) or associated with colloids (Wetzel, 1983). Total phosphorus was the most commonly reported phosphorus species in

the data sets for the EIWA study unit. Sources of phosphorus include wastewater-treatment-plant effluent, detergents, fertilizers, and sediment from surface runoff.

## Concentrations

Nutrient data were statistically summarized for all monitoring sites from the IDNR, MPCA, UIIHR, and USGS data sets (table 4). Statistical summary concentrations for each monitoring site are presented as a minimum, 25th percentile, 50th percentile (median), 75th percentile, maximum, and mean.

Nutrient concentrations were variable at the monitoring sites. Ammonia concentrations ranged from <0.10 to 28 mg/L. However, the 28 mg/L ammonia concentration for one sample is unusually high and unexplained. The median ammonia concentrations ranged from <0.10 to 0.77 mg/L (table 4). Nitrate concentrations ranged from <0.10 to 26 mg/L. The median nitrate concentrations were 2.2 to 8.8 mg/L with 12 of the 17 monitoring sites having median nitrate concentrations ranging from 4.0 to 6.0 mg/L. Total phosphorus concentrations ranged from <0.10 to 5.4 mg/L. Median concentrations of total phosphorus ranged from <0.10 to 0.66 mg/L (table 4).

## Relations Between Concentrations and Streamflow

The concentration of nutrients associated with nonpoint-source inputs generally increases as streamflow increases because of runoff and (or) agricultural tile drain flow, which result in a positive relation between concentration and streamflow. The opposite effect typically is observed for point-source concentrations. Concentrations of constituents associated with point-source locations decrease in the stream due to dilution as streamflow increases, resulting in a negative relation between concentration and streamflow. Point sources often have higher concentrations at the lowest streamflows as the point-source concentrations input to the stream are not being diluted during periods of low streamflow. These relations are complex and are affected by antecedent soil conditions, timing of fertilizer application, land cover, and the location, duration, and intensity of precipitation. A mixture of point and nonpoint sources can obscure any relation between concentration and streamflow.

The ideal situation is to collect water-quality samples over a range of flow conditions to limit bias in the data. Water-quality samples collected over a long period of time may tend to include results from a range of flow conditions. In addition, larger streams generally have a better distribution of samples in the data sets when compared to small streams. High flow in the larger streams is generally of longer duration, resulting in an increased likelihood of obtaining samples at peak streamflows when compared to collecting samples at high flow in small streams. Small streams have streamflows that peak quickly (within a few hours) during runoff, making runoff samples more difficult to obtain. The monitoring sites selected for this report were on larger streams and had long-term water-quality records.

Nutrient concentration and streamflow were plotted for all the IDNR, MPCA, UIIHR, and USGS monitoring sites with the exception of three sites. At two of the three unused monitoring sites, streamflow data were not available (site 1, Cedar River near Lansing, Minnesota, and site 4, Shell Rock River near Gordonsville, Minnesota), and at the third monitoring site (site 14, South Skunk River near Ames, Iowa), long-term nutrient data were lacking. In addition, for the plots of ammonia plus organic nitrogen concentrations versus streamflow, site 8 (Cedar River near Palo, Iowa) was not included because of a lack of ammonia plus organic nitrogen data for this site. Plots of total phosphorus versus streamflow were not prepared for site 2 (Cedar River near Austin, Minnesota) and site 9 (Iowa River near South Amana, Iowa) because of the lack of phosphorus data at these sites.

The most typical relations observed between nutrients and streamflow at selected monitoring sites on the Cedar, Iowa, and Skunk Rivers are illustrated in LOWESS plots (figs. 6–9). The LOWESS plots for the remaining monitoring sites are shown in figures 10–13. In general, nutrient concentrations were not linearly related to streamflow. In other words, as streamflow increased, there was not always a corresponding increase in nutrient concentrations, especially at the highest rates of flow. There may be a “dilution effect” of nutrient concentrations at the highest flows as more water originates directly from precipitation. Another explanation is that there is simply a lack of representative water-quality samples at the highest flows. Also, concentrations tend to be higher for most nutrient constituents on the rising limb of the hydrograph than on the falling limb.

**Table 4.** Statistical summary of nutrient concentrations in samples from surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[mg/L, milligrams per liter; <, less than; --, no data]

Constituent	Number of samples	Minimum concentration measured (mg/L)	Percentile			Maximum concentration measured (mg/L)	Mean concentration measured (mg/L)
			25	50 (median) (mg/L)	75		
Cedar River near Lansing, Minn. (site 1, fig. 1)							
Total nitrogen, as N	177	1.3	3.5	5.4	7.9	18	5.9
Ammonia, as N	196	<.10	<.10	.14	.32	3.9	.28
Organic nitrogen, as N	177	<.10	.49	.69	1.0	3.7	.81
Nitrite plus nitrate, as N	196	.08	2.0	4.0	7.0	17	4.6
Orthophosphate, dissolved, as P	--	--	--	--	--	--	--
Total phosphorus, as P	189	<.10	.12	.17	.27	.97	.22
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Cedar River near Austin, Minn. (site 2, fig. 1)							
Total nitrogen, as N	226	1.5	4.9	6.4	8.6	14	6.8
Ammonia, as N	246	<.10	.25	.59	1.4	4.9	1.0
Organic nitrogen, as N	226	<.10	.78	1.1	1.5	6.9	1.2
Nitrite plus nitrate, as N	246	<.10	2.7	3.9	6.3	12	4.5
Orthophosphate, dissolved, as P	--	--	--	--	--	--	--
Total phosphorus, as P	246	<.10	.35	.53	.82	2.6	.43
Dissolved phosphorus, as P	2	.26	--	--	--	.57	.42
Cedar River near Charles City, Iowa (site 3, fig. 1)							
Total nitrogen, as N	208	1.6	5.0	6.3	8.1	13	6.4
Ammonia, as N	197	<.10	<.10	<.10	.20	1.7	.17
Organic nitrogen, as N	18	.19	.51	.82	1.0	2.5	.84
Nitrite plus nitrate, as N	210	<.10	3.8	5.6	7.2	11	5.5
Orthophosphate, dissolved, as P	133	<.10	<.10	.11	.20	.70	.16
Total phosphorus, as P	198	<.10	.19	.22	.30	1.2	.27
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Shell Rock River near Gordonsville, Minn. (site 4, fig. 1)							
Total nitrogen, as N	226	.39	5.0	6.8	8.6	31	7.4
Ammonia, as N	245	<.10	.10	.29	1.0	28	1.2
Organic nitrogen, as N	226	<.10	1.8	2.7	3.6	13	2.9
Nitrite plus nitrate, as N	245	<.10	.68	2.2	4.5	26	3.2
Orthophosphate, dissolved, as P	--	--	--	--	--	--	--
Total phosphorus, as P	246	<.10	.40	.66	1.2	5.4	.97
Dissolved phosphorus, as P	--	--	--	--	--	--	--
West Fork Cedar River near Finchford, Iowa (site 5, fig. 1)							
Total nitrogen, as N	112	.15	4.4	5.9	8.4	14	6.0
Ammonia, as N	112	<.10	<.10	<.10	<.10	1.2	.10
Organic nitrogen, as N	1	.35	--	--	--	.35	.35
Nitrite plus nitrate, as N	112	<.10	3.4	5.4	7.8	13	5.4

**Table 4.** Statistical summary of nutrient concentrations in samples from surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95—Continued

[mg/L, milligrams per liter; <, less than; --, no data]

Constituent	Number of samples	Minimum concentration measured (mg/L)	Percentile			Maximum concentration measured (mg/L)	Mean concentration measured (mg/L)
			25	50 (median) (mg/L)	75		
West Fork Cedar River near Finchford, Iowa (site 5, fig. 1)—Continued							
Orthophosphate, dissolved, as P	112	<.10	<.10	<.10	.10	.60	.10
Total phosphorus, as P	101	<.10	<.10	.12	.20	.70	.18
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Cedar River at Cedar Falls, Iowa (site 6, fig. 1)							
Total nitrogen, as N	113	0.24	3.8	5.6	7.4	17	5.9
Ammonia, as N	114	<.01	.01	.04	.17	1.30	.15
Organic nitrogen, as N	112	.15	.62	.98	1.6	12	1.2
Nitrite plus nitrate, as N	129	<.10	2.0	4.1	6.2	16	4.2
Orthophosphate, dissolved, as P	69	<.10	<.10	<.10	.15	.46	.11
Total phosphorus, as P	114	<.10	.14	.19	.28	.76	.22
Dissolved phosphorus, as P	70	<.10	<.10	.10	.18	.48	.12
Cedar River at Gilbertville, Iowa (site 7, fig. 1)							
Total nitrogen, as N	77	.66	3.9	5.6	7.2	10	5.7
Ammonia, as N	79	<.01	.01	.06	.21	1.8	.24
Organic nitrogen, as N	77	.02	.62	1.4	1.7	4.6	1.3
Nitrite plus nitrate, as N	79	<.10	2.3	4.1	6.0	8.8	4.2
Orthophosphate, dissolved, as P	21	<.10	<.10	.12	.17	.42	.12
Total phosphorus, as P	79	<.10	.25	.31	.44	.86	.35
Dissolved phosphorus, as P	18	<.10	<.10	.16	.23	.48	.18
Cedar River near Palo, Iowa (site 8, fig. 1)							
Total nitrogen, as N	--	--	--	--	--	--	--
Ammonia, as N	546	<.10	<.10	<.10	.28	1.6	.23
Organic nitrogen, as N	--	--	--	--	--	--	-
Nitrite plus nitrate, as N	550	<.10	2.1	5.0	7.0	24	4.9
Orthophosphate, dissolved, as P	509	<.10	<.10	.10	.20	1.8	.15
Total phosphorus, as P	477	<.10	.20	.30	.44	3.1	.41
Dissolved phosphorus, as P	31	<.10	<.10	<.10	<.10	<.10	<.10
Iowa River near South Amana, Iowa (site 9, fig. 1)							
Total nitrogen, as N	49	3.6	5.6	6.2	8.6	15	6.8
Ammonia, as N	527	<.10	<.10	<.10	.20	3.7	.20
Organic nitrogen, as N	3	.49	--	--	--	.83	.60
Nitrite plus nitrate, as N	500	<.10	2.7	4.9	7.8	20	5.3
Orthophosphate, dissolved, as P	91	<.10	<.10	<.10	.13	1.1	.11
Total phosphorus, as P	7	<.10	--	--	--	.50	.15
Dissolved phosphorus, as P	102	<.10	<.10	<.10	.12	1.0	.10
Iowa River at Iowa City, Iowa (site 10, fig. 1)							
Total nitrogen, as N	88	.55	3.4	4.6	6.1	14	4.9
Ammonia, as N	598	<.10	<.10	.13	.30	4.1	.28
Organic nitrogen, as N	40	<.10	.56	.86	1.2	5.0	1.0
Nitrite plus nitrate, as N	563	<.10	2.0	4.2	6.7	15	4.5

**Table 4.** Statistical summary of nutrient concentrations in samples from surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95—Continued

[mg/L, milligrams per liter; <, less than; --, no data]

Constituent	Number of samples	Minimum concentration measured (mg/L)	Percentile			Maximum concentration measured (mg/L)	Mean concentration measured (mg/L)
			25	50 (median) (mg/L)	75		
Iowa River at Iowa City, Iowa (site 10, fig. 1)—Continued							
Orthophosphate, dissolved, as P	141	<.10	<.10	<.10	.12	1.1	.11
Total phosphorus, as P	44	<.10	<.10	<.10	.19	1.4	.14
Dissolved phosphorus, as P	128	<.10	<.10	<.10	<.10	.72	<.10
English River near Riverside, Iowa (site 11, fig. 1)							
Total nitrogen, as N	106	0.45	2.4	6.0	8.3	19	6.0
Ammonia, as N	106	<.10	<.10	.08	.30	2.7	.28
Organic nitrogen, as N	--	--	--	--	--	--	--
Nitrite plus nitrate, as N	106	<.10	1.4	4.3	6.9	16	4.7
Orthophosphate, dissolved, as P	106	<.10	<.10	<.10	.15	.80	.12
Total phosphorus, as P	95	<.10	.10	.20	.40	2.3	.38
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Iowa River at Columbus Junction, Iowa (site 12, fig. 1)							
Total nitrogen, as N	93	1.8	4.4	6.2	8.2	13	6.4
Ammonia, as N	93	<.10	<.10	.20	.50	2.2	.40
Organic nitrogen, as N	1	3.0	--	--	--	3.0	--
Nitrite plus nitrate, as N	93	<.10	2.2	4.7	6.6	12	4.6
Orthophosphate, dissolved, as P	93	<.10	.10	.20	.20	.60	.18
Total phosphorus, as P	93	<.10	.30	.40	.60	1.1	.42
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Iowa River at Wapello, Iowa (site 13, fig. 1)							
Total nitrogen, as N	116	1.2	5.2	6.6	8.6	15	6.8
Ammonia, as N	115	<.01	.02	.06	.16	1.6	.16
Organic nitrogen, as N	114	.35	.90	1.5	1.9	5.3	1.5
Nitrite plus nitrate, as N	117	<.10	3.5	5.3	7.0	15	5.2
Orthophosphate, dissolved, as P	82	<.10	<.10	.11	.15	.29	.11
Total phosphorus, as P	116	<.10	.20	.27	.38	1.0	.31
Dissolved phosphorus, as P	114	<.10	<.10	.14	.19	.39	.14
South Skunk River near Ames, Iowa (site 14, fig. 1)							
Total nitrogen, as N	2	3.8	--	--	--	4.6	4.2
Ammonia, as N	43	.41	.61	.77	1.0	7.2	1.1
Organic nitrogen, as N	2	.89	--	--	--	.97	.93
Nitrite plus nitrate, as N	41	.17	.99	2.4	4.0	9.2	2.9
Orthophosphate, dissolved, as P	2	1.2	--	--	--	1.9	1.6
Total phosphorus, as P	45	.19	.29	.37	.64	4.0	.62
Dissolved phosphorus, as P	--	--	--	--	--	--	--
South Skunk River near Cambridge, Iowa (site 15, fig. 1)							
Total nitrogen, as N	77	2.2	7.4	9.4	13	23	10
Ammonia, as N	78	<.10	<.10	<.10	.10	1.7	.15
Organic nitrogen, as N	--	--	--	--	--	--	--
Nitrite plus nitrate, as N	78	1.4	6.8	8.8	12	22	9.5

**Table 4.** Statistical summary of nutrient concentrations in samples from surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95—Continued

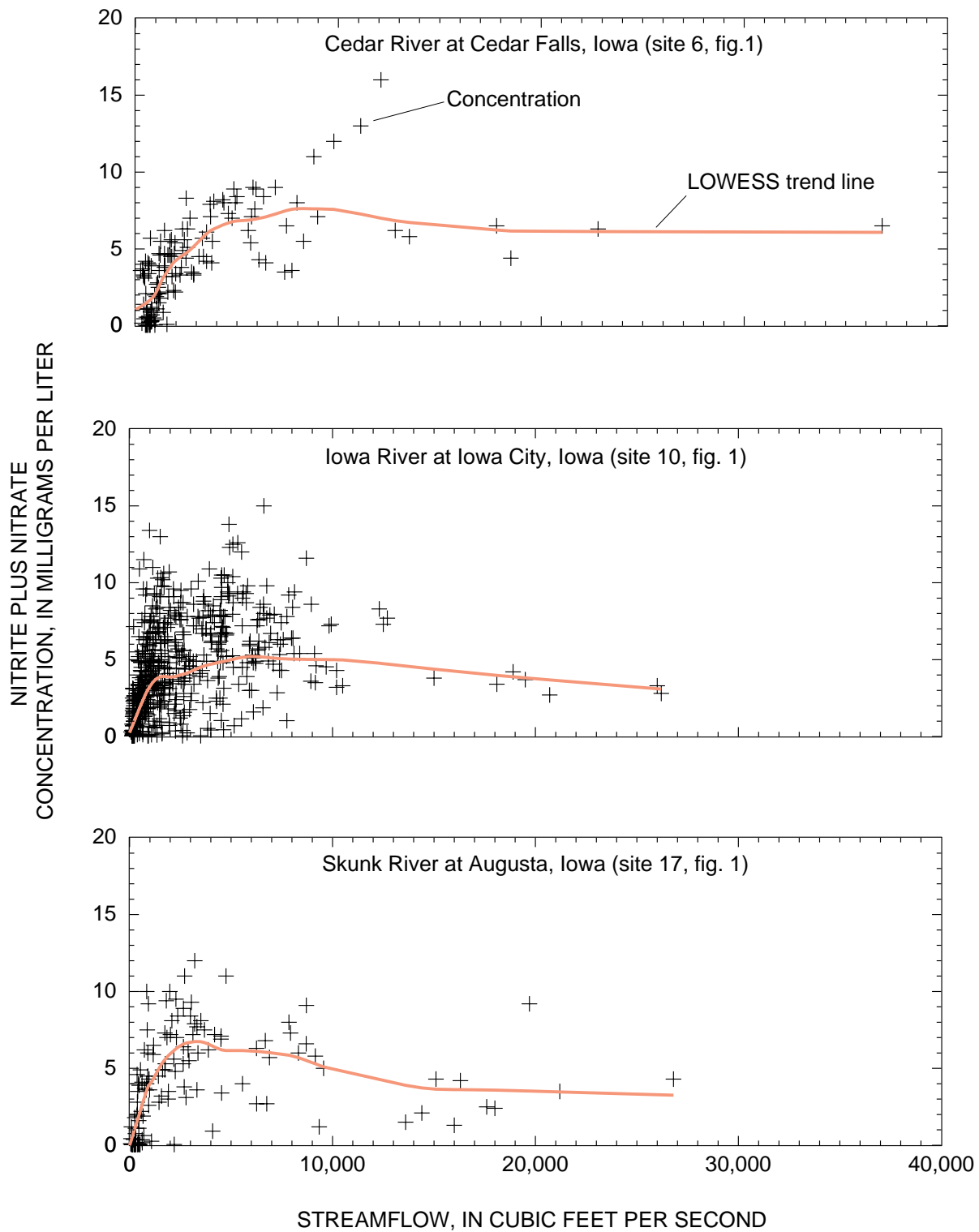
[mg/L, milligrams per liter; <, less than; --, no data]

Constituent	Number of samples	Minimum concentration measured (mg/L)	Percentile			Maximum concentration measured (mg/L)	Mean concentration measured (mg/L)
			25	50 (median) (mg/L)	75		
South Skunk River near Cambridge, Iowa (site 15, fig. 1)—Continued							
Orthophosphate, dissolved, as P	78	<.10	.20	.30	.70	4.2	.65
Total phosphorus, as P	77	.10	.30	.40	.90	4.5	.79
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Cedar Creek near Oakland Mills, Iowa (site 16, fig. 1)							
Total nitrogen, as N	111	0.60	2.3	4.9	8.2	16	5.5
Ammonia as N	111	<.10	<.10	<.10	.10	2.2	.16
Organic nitrogen, as N	--	--	--	--	--	--	--
Nitrite plus nitrate, as N	111	<.10	1.0	3.7	7.6	13	4.4
Orthophosphate, dissolved, as P	110	<.10	<.10	.10	.20	.90	.14
Total phosphorus, as P	101	<.10	.20	.20	.40	1.9	.32
Dissolved phosphorus, as P	--	--	--	--	--	--	--
Skunk River at Augusta, Iowa (site 17, fig. 1)							
Total nitrogen, as N	115	.55	3.4	5.7	8.1	13	5.8
Ammonia, as N	117	<.01	.02	.06	.17	1.5	.17
Organic nitrogen, as N	113	.09	.71	1.0	1.6	5.7	1.3
Nitrite plus nitrate, as N	123	<.10	1.8	4.1	6.8	12	4.4
Orthophosphate, dissolved, as P	83	<.10	<.10	<.10	.13	.24	<.10
Total phosphorus, as P	115	<.10	.15	.23	.35	1.7	.29
Dissolved phosphorus, as P	115	<.10	<.10	.12	.16	.25	.11

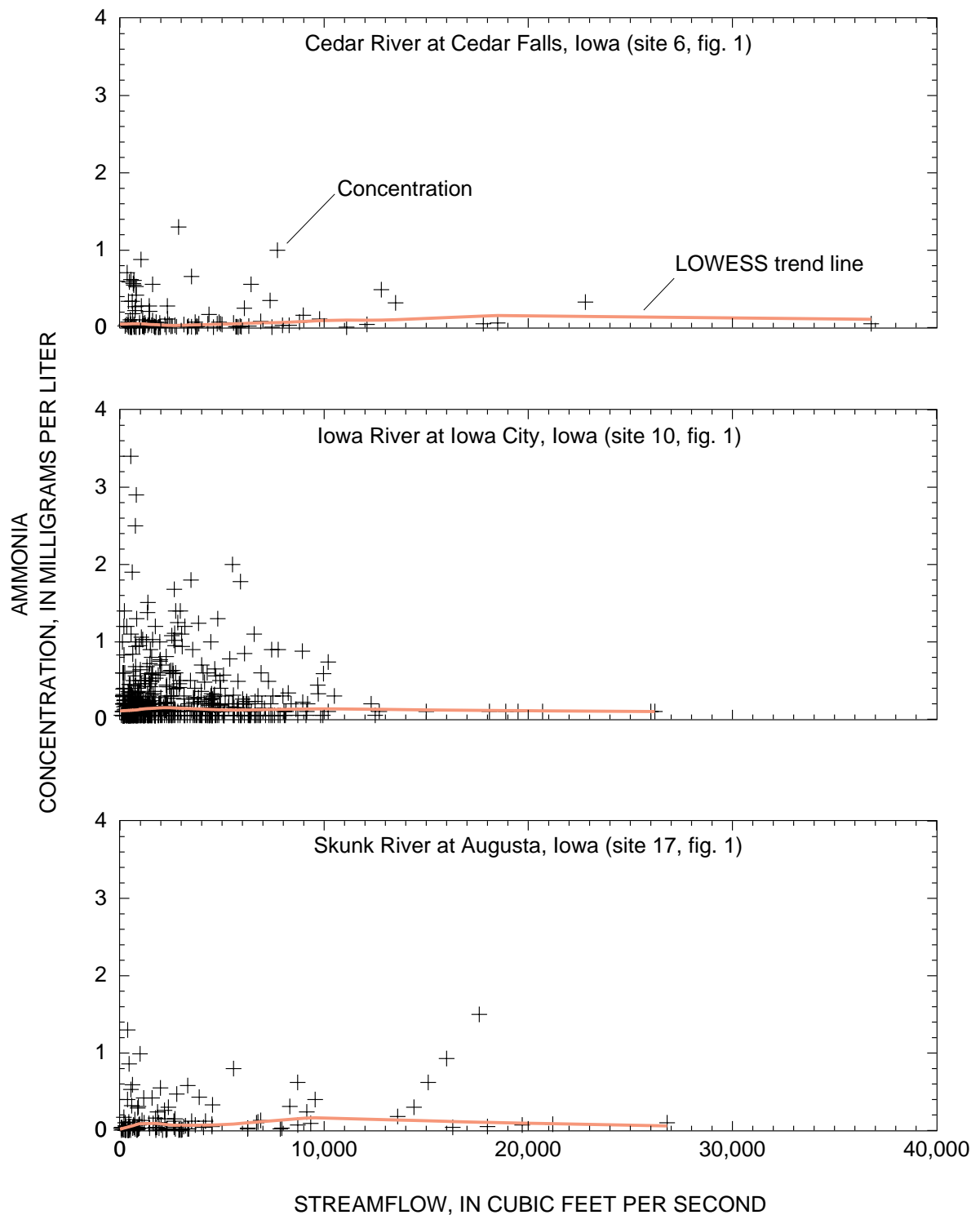
One of the trends observed was a positive correlation of nitrate concentrations with streamflow. The LOWESS plots of nitrate versus streamflow (fig. 6) show nitrate concentrations increasing with higher rates of streamflow until extreme streamflows where nitrate concentrations tend to “level off” and even decrease. During storms, nitrate that has accumulated on the land surface and in the soil is transported to streams by water flowing overland and through soils and by shallow ground water. Typically, the LOWESS plots for nitrate concentrations show a steep positive increase in concentration as streamflow begins to increase. The decrease in concentration at the highest rate of streamflow indicates that after extended periods of runoff, nitrate available for transport to streams becomes depleted, and further rainfall and runoff dilute the nitrate concentrations.

The ammonia and ammonia plus organic nitrogen LOWESS plots do not show a correlation with streamflow (figs. 7, 8, 11, and 12). This may be expected as ammonia is oxidized rather quickly to nitrate during surface-water runoff. Typically, nitrate is the dominant nitrogen species at the surface-water monitoring sites rather than ammonia or ammonia plus organic nitrogen. Approximately 60 to 94 percent of the median concentrations of total nitrogen consisted of nitrate (table 4). The one exception was the Shell Rock River near Gordonsville, Minnesota (site 4), which had a median nitrate of only 32 percent of the total nitrogen.

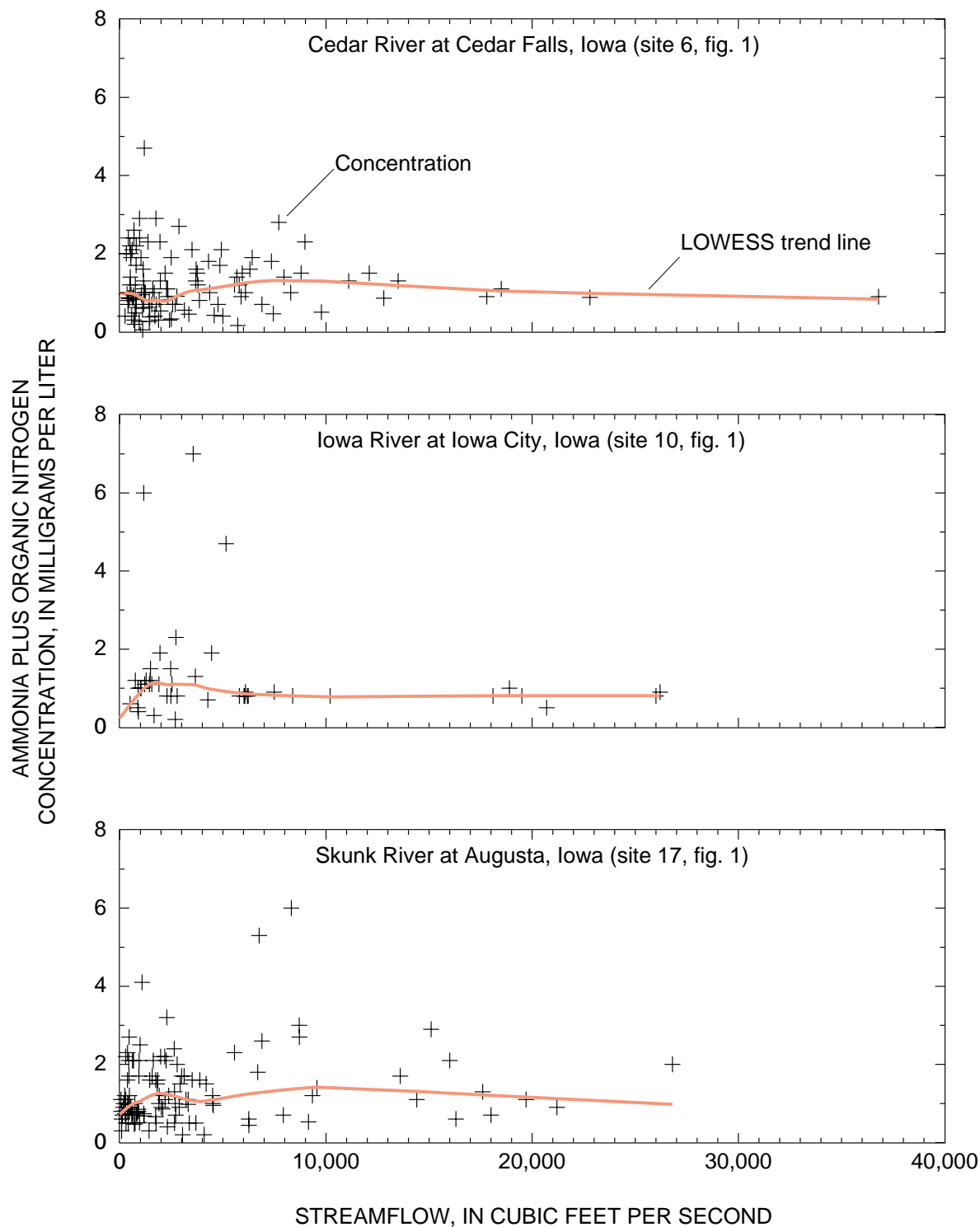
Typically, phosphorus shows a slight positive correlation with increasing streamflow. However, the positive correlation for increasing phosphorus concentrations with increasing streamflow differs from and is not as strong as the positive correlation of nitrate concentrations that increase with streamflow.



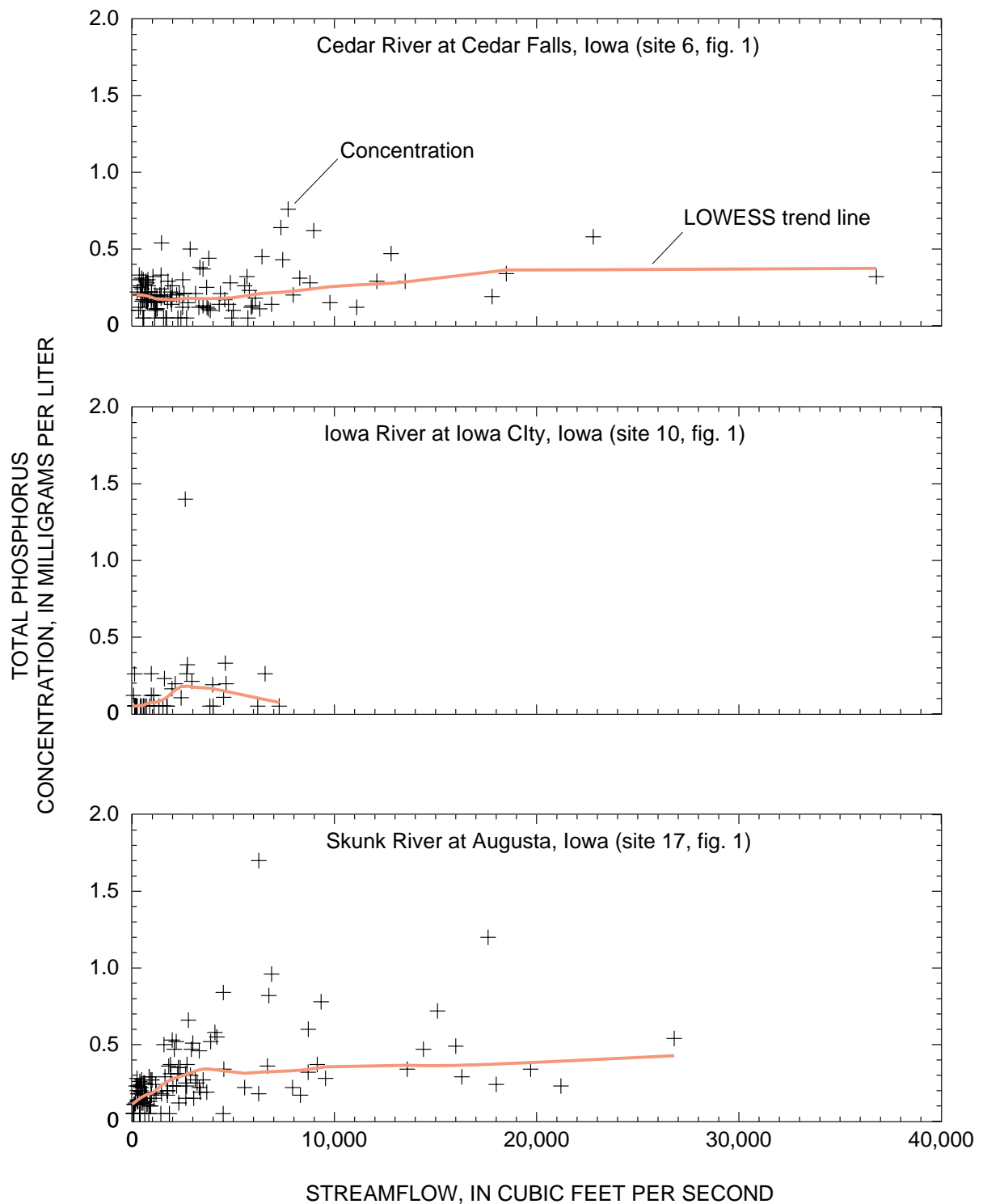
**Figure 6.** Relation of nitrite plus nitrate concentrations to streamflow at selected surface-water-quality sites in the Eastern Iowa Basins study unit, 1970–95.



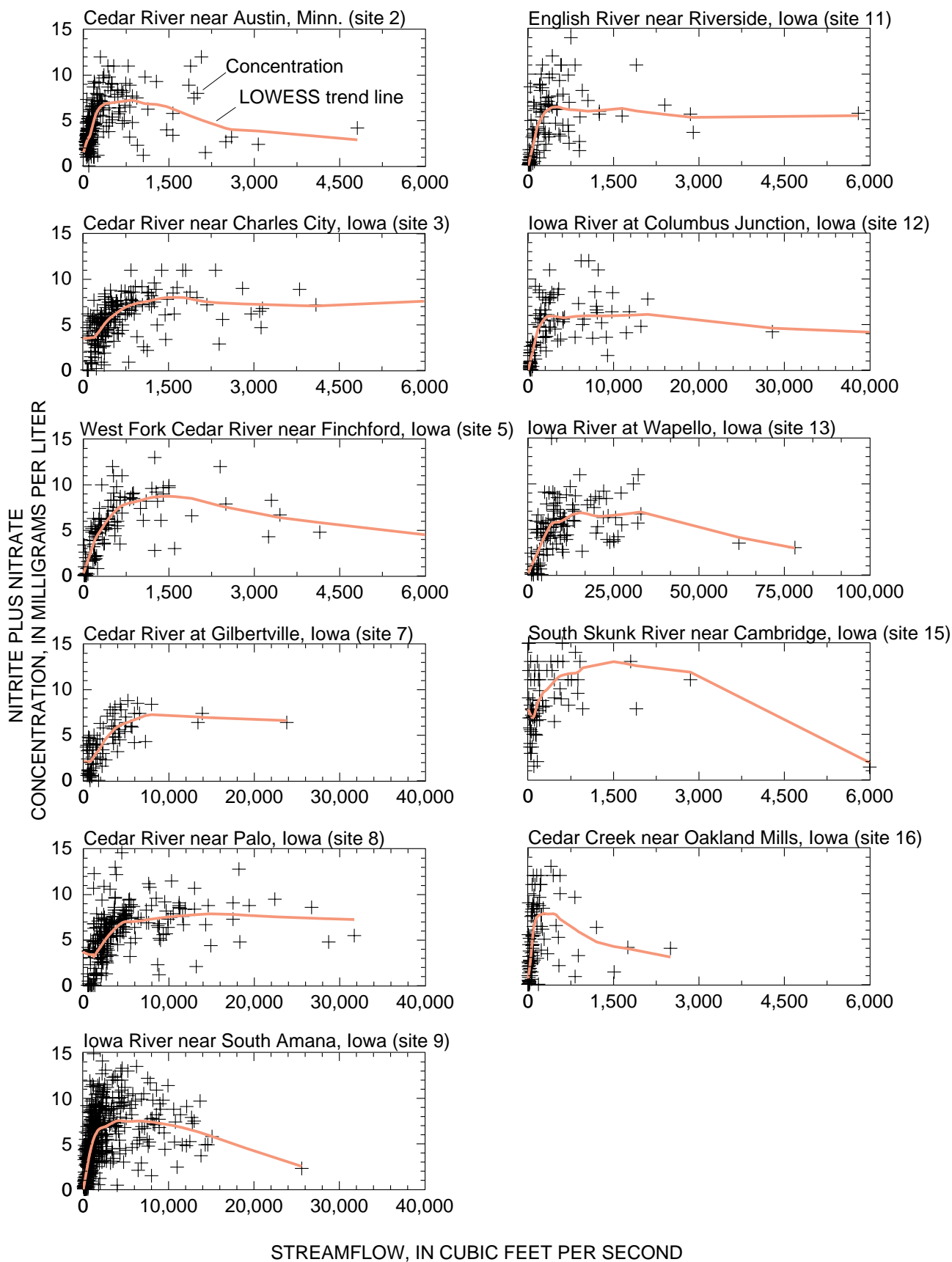
**Figure 7.** Relation of ammonia concentrations to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



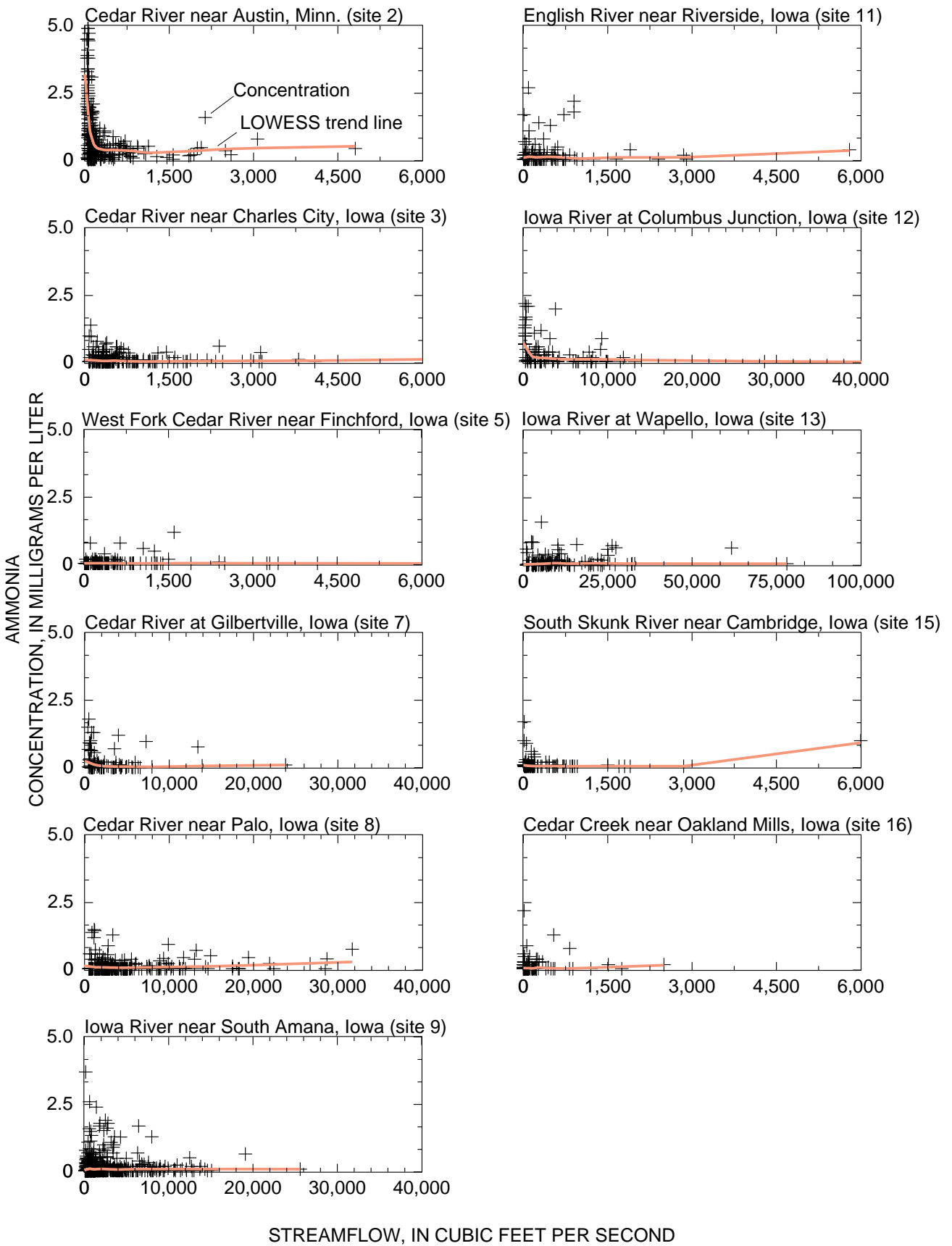
**Figure 8.** Relation of ammonia plus organic nitrogen to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



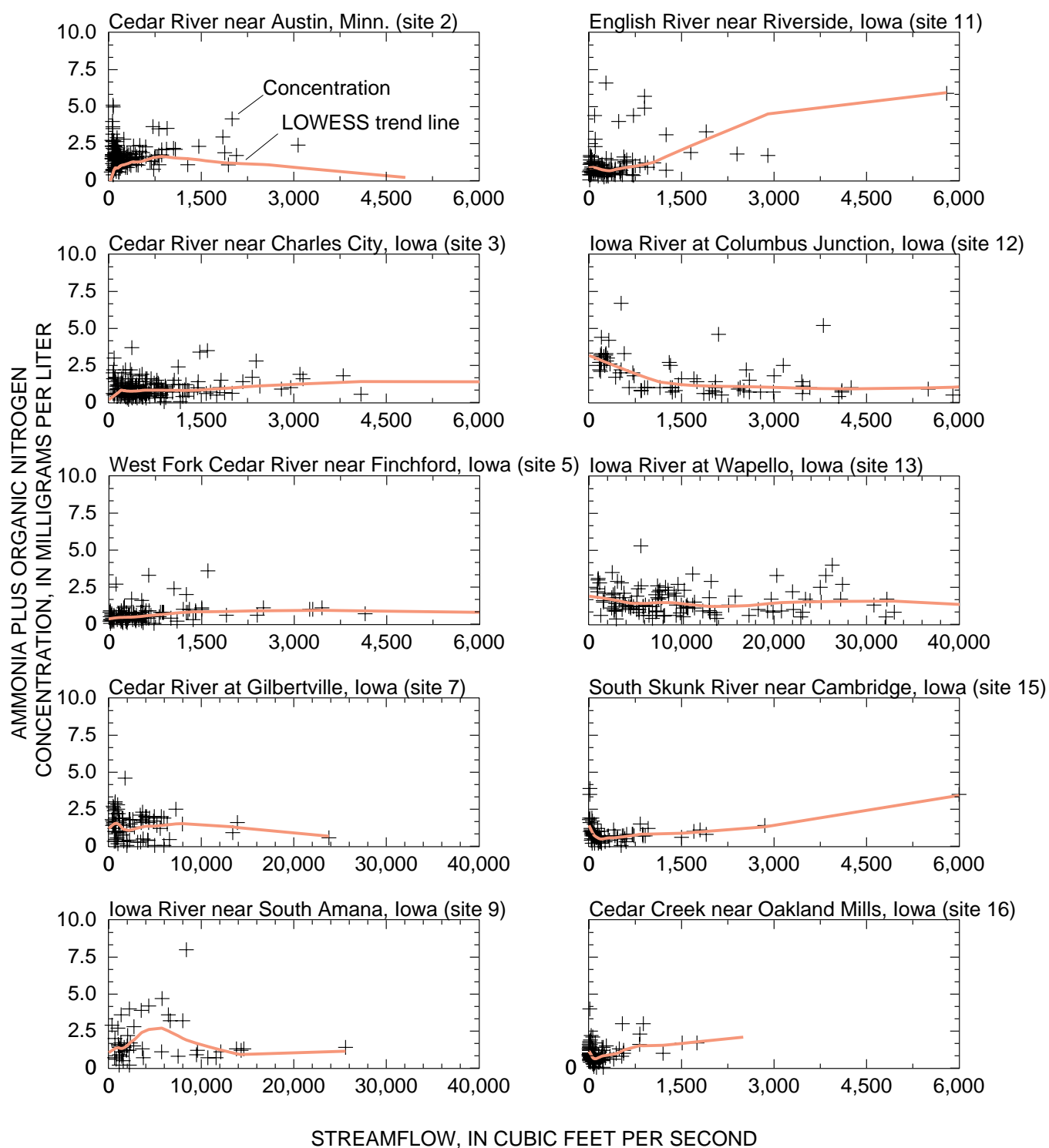
**Figure 9.** Relation of total phosphorus to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



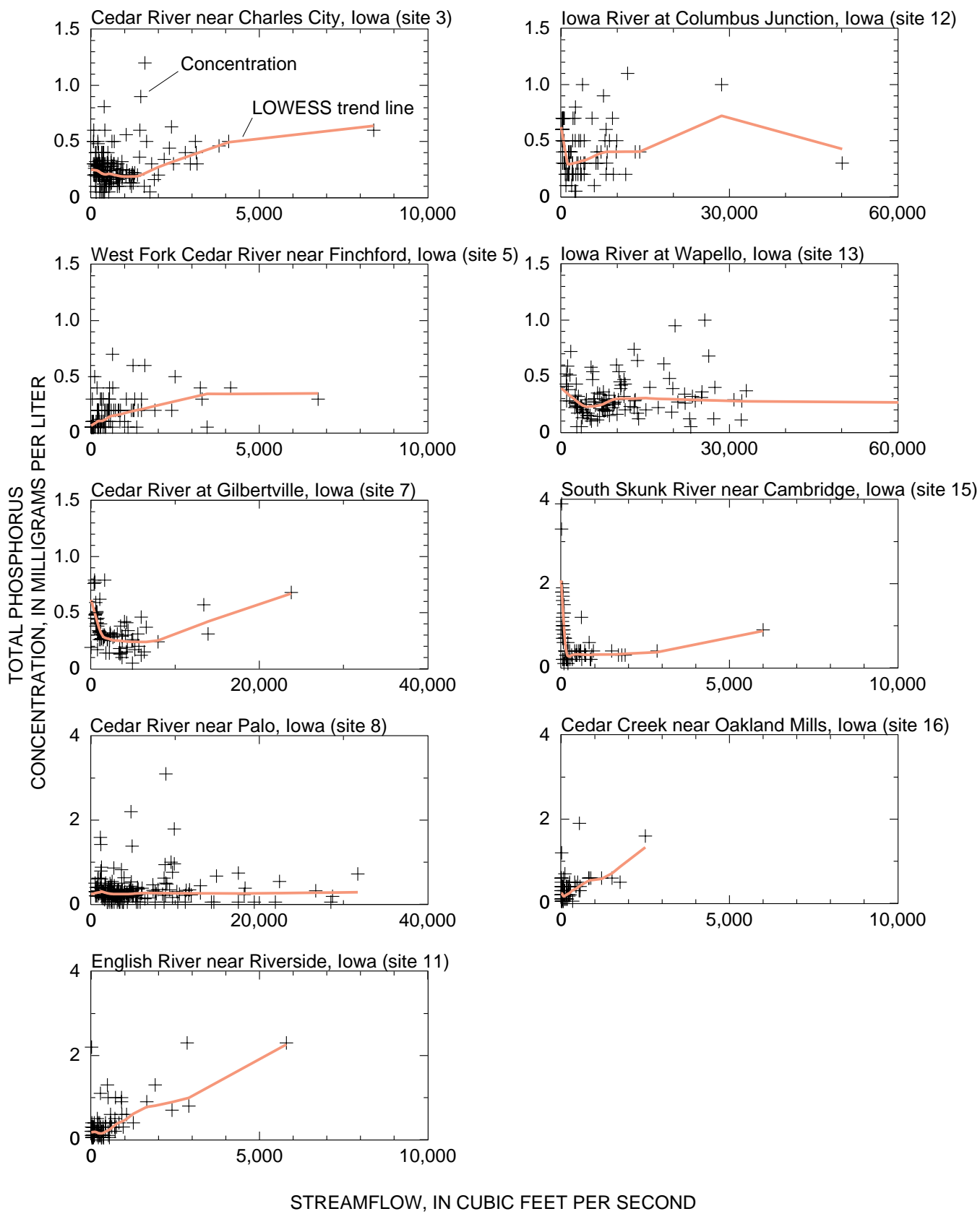
**Figure 10.** Relation of nitrite plus nitrate concentrations to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



**Figure 11.** Relation of ammonia concentrations to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



**Figure 12.** Relation of ammonia plus organic nitrogen concentrations to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



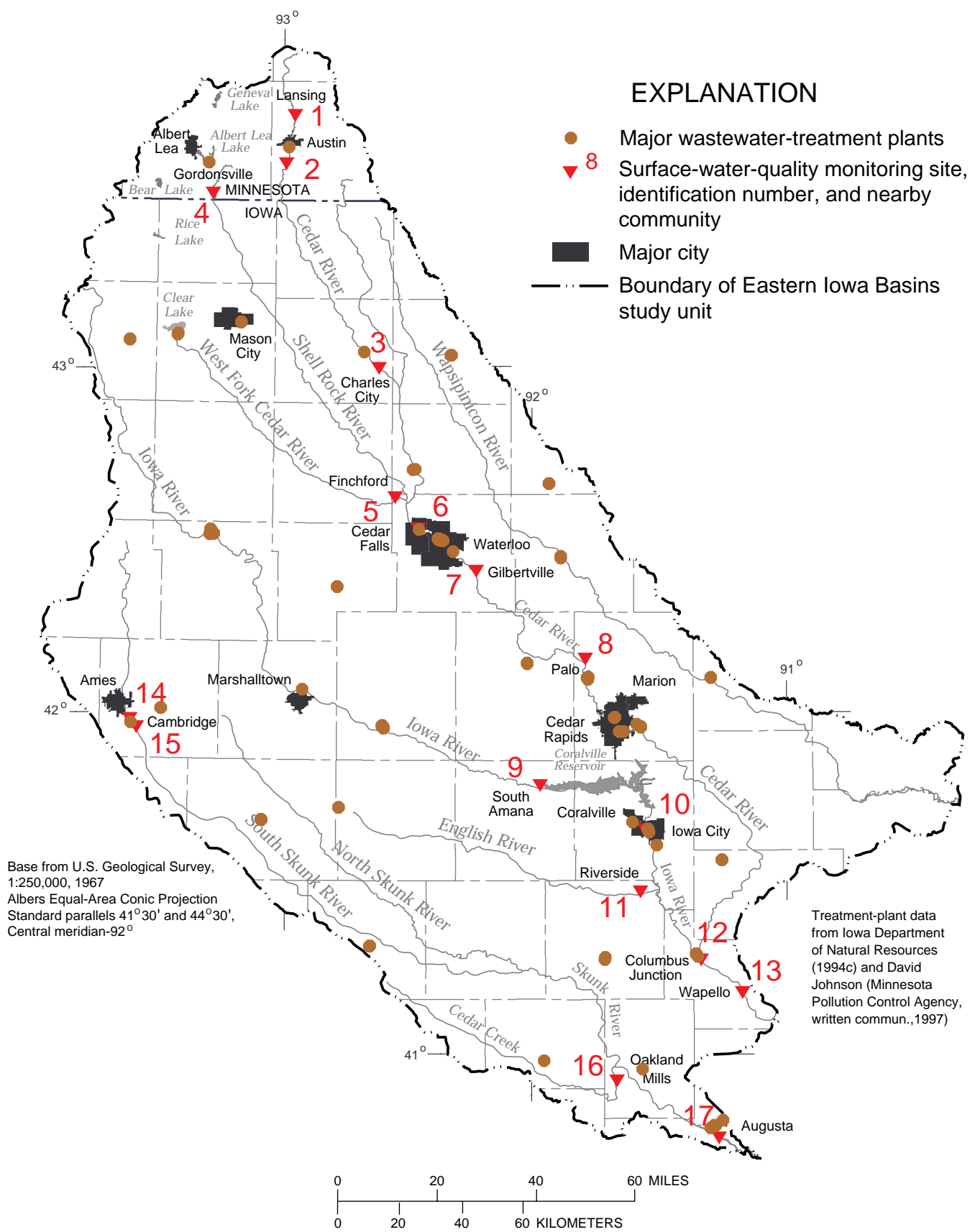
**Figure 13.** Relation of total phosphorus concentrations to streamflow at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.

Generally, the total phosphorus concentrations show a gradual increase with increasing streamflow (figs. 9 and 13), whereas nitrate concentrations decrease at the higher streamflows (figs. 6 and 10). Total phosphorus concentrations also show a positive correlation at low streamflows (generally the lowest 10 percent of the total streamflow), but the slope of the trend line for this increase is more gradual when compared to the increase of nitrate concentrations at these same streamflows. The larger rivers generally had their lowest 10 percent of total streamflow ranging from 0 to 3,000 ft<sup>3</sup>/s, while smaller streams had their lowest 10 percent of total streamflow ranging from 0 to 1,500 ft<sup>3</sup>/s. For example, compare sites 6, 10, and 17 for nitrate in figure 6 (p. 24) with total phosphorus in figure 9 (p. 27) for streamflows from 0 to 3,000 ft<sup>3</sup>/s. Also compare site 8 for nitrate (fig. 10, p. 28) with total phosphorus (fig. 13, p. 31) for streamflow from 0 to 3,000 ft<sup>3</sup>/s. This pattern of nitrate concentrations having a steeper slope for their trend line when compared to total phosphorus at low streamflows also was seen for other monitoring sites on smaller streams such as at sites 3, 5, 11, and 16 for streamflows from 0 to 1,500 ft<sup>3</sup>/s (compare figs. 10 and 13). In contrast, possible point sources for total phosphorus are indicated when the trend line for total phosphorus concentrations are greater at low (0 to 1,500 ft<sup>3</sup>/s) streamflows (negative trend line) such as at sites 7, 12, 13, and 15 (fig. 13, p. 31).

The different trends in correlations between nitrate and total phosphorus concentrations and streamflow may reflect differences in transport processes for these constituents in the hydrologic system. There may be several possibilities. One hypothesis is that nitrate is formed in the oxidized, shallow soil zone and may be flushed out during increasing flows through tile drains and interflow. Logan (1978) showed that most of the nitrate enters streams via tile drainage and interflow in the Maumee River Basin in Ohio. However, the LOWESS plots are not for a single hydrograph period or one runoff event. It may be a case of higher base flows that are contributing to higher nitrate concentrations. Hallberg (1989) and Seigley and others (1993) state that high nitrate concentrations occur in surface water during high ground-water base-flow periods. Another important component to consider is the biological aspect. At low flows during the summer and fall, uptake by plants and the algae in the streams may use much of the nitrate. These effects may be overshadowed with increasing streamflow.

The gradual positive trend of increasing total phosphorus concentrations with increasing streamflow may be related to the increased transport of sediment. Phosphate adsorbs to soils, sediments, and iron hydroxides and can be transported by erosion (Hem, 1985, p. 126). Meybeck (1982) estimated that the particulate forms of phosphorus constituted about 95 percent of the total phosphorus carried in river water. Total phosphorus concentrations often follow the concentration pattern for suspended sediment (Baker, 1988). Perhaps much of the total phosphorus is transported as sediment and not in the dissolved phase like nitrate. This hypothesis might explain why the slope of the LOWESS trend line for total phosphorus did increase, but it was not as steep at smaller streamflows (the lower 10 percent of streamflow) when compared to the slope of the nitrate LOWESS trend line. The total phosphorus LOWESS trend line has a more gradual positive slope than the nitrate LOWESS trend line, perhaps because nitrate is transported to surface water by overland flow, interflow, and tile drains in the dissolved phase. It is likely that concentrations of nitrate show a higher positive correlation with streamflow at the low to middle streamflow discharges as nitrate is transported rapidly during these periods.

The LOWESS plots for some monitoring sites clearly showed point-source effects for ammonia, ammonia plus organic nitrogen, and total phosphorus. At low flow, the monitoring sites with possible point-source effects have a negative slope for the LOWESS line when concentrations of ammonia, ammonia plus organic nitrogen, and total phosphorus are plotted versus streamflow. Two monitoring sites—Cedar River near Austin, Minnesota (site 2), and Iowa River at Columbus Junction (site 12)—indicate point-source effects for ammonia (fig. 11). Three monitoring sites—Cedar River at Gilbertville (site 7), Iowa River at Columbus Junction (site 12), and South Skunk River near Cambridge (site 15)—indicate point-source effects for ammonia plus organic nitrogen (fig. 12). Four monitoring sites—Cedar River at Gilbertville (site 7), Iowa River at Columbus Junction (site 12), Iowa River at Wapello (site 13), and South Skunk River near Cambridge (site 15)—indicate point-source effects for total phosphorus (fig. 13). The point-source effects may be from major wastewater-treatment plants located relatively close upstream from the monitoring sites (fig. 14). Major wastewater-treatment plants are those permitted for discharge of effluent at one million gallons per day or greater (Charles Furrey, Iowa Department of Natural Resources, oral commun., 1998).



**Figure 14.** Major wastewater-treatment plants in the Eastern Iowa Basins study unit, 1994. Major wastewater plants are permitted for one million gallons or greater discharge.

The Columbus Junction site shows the greatest possible point-source effect for ammonia, ammonia plus organic nitrogen, and total phosphorus (fig. 15). The Columbus Junction monitoring site is located less than 1 mi downstream from industrial wastewater discharges at Columbus Junction. A previous water-quality study by UHL documented greater ammonia concentrations in the Iowa River downstream from Columbus Junction (University of Iowa Hygienic Laboratory, 1988). The Iowa River at Wapello monitoring site (site 13), approximately 13 mi downstream from Columbus Junction, also shows some of the effects seen at the Columbus Junction site during low flow for ammonia plus organic nitrogen and total phosphorus (fig. 15). However, no relation at the Wapello site (fig. 15) can be identified for ammonia with streamflow. The decrease in ammonia concentration from the Columbus Junction site (site 12) to the Wapello site (site 13) could be caused by oxidation of ammonia to nitrate in the stream or by dilution effects from the Cedar River. The negative slope of the LOWESS trend lines for ammonia plus organic nitrogen and total phosphorus concentrations at the Wapello site are not as pronounced as at the Columbus Junction site but are still present. The LOWESS plots indicate that the point-source effects observed at low flow at Columbus Junction also are observed downstream at the Wapello site. Dilution effects by the Cedar River do not completely negate these effects shown upstream.

### Seasonal Variability

The nutrient concentrations in streams and rivers in some cases may vary by time of year as well as streamflow at the time of sample collection. The effects of season and streamflow generally are closely related in the EIWA study unit. Streamflow is usually the highest during the spring (April–June) and lowest during the late summer and early fall (August, September, and October). In addition, plant growth (terrestrial and aquatic) and their related nutrient uptake are controlled to a large extent by the climatic variations between the agricultural growing and nongrowing seasons. The agricultural growing season generally is from April through September.

Monthly data for this report were analyzed by season—winter (January–March), spring (April–June), summer (July–September), and fall

(October–December). Figure 16 shows the number of nitrate samples collected per season. Sample distribution by season for the other nutrients is similar. Generally, the nutrient samples showed a fairly even distribution by season for each monitoring site, although there were exceptions. There were slightly more nutrient samples collected during the spring and summer than during the fall and winter at Cedar River near Lansing, Minnesota (site 1); Cedar River near Austin, Minnesota (site 2); Shell Rock River near Gordonsville, Minnesota (site 4); Cedar River at Gilbertville (site 7), Iowa River near South Amana (site 9); Iowa River at Iowa City (site 10); South Skunk River near Ames (site 14); and Skunk River at Augusta (site 17) (fig. 16). Boxplots were completed for nutrient concentration by month and season for all monitoring sites, although only selected monitoring sites for the Cedar, Iowa, and Skunk Rivers are shown in this report (figs. 17–20, p. 38–41). The selected monitoring sites are representative of trends observed at all the monitoring sites.

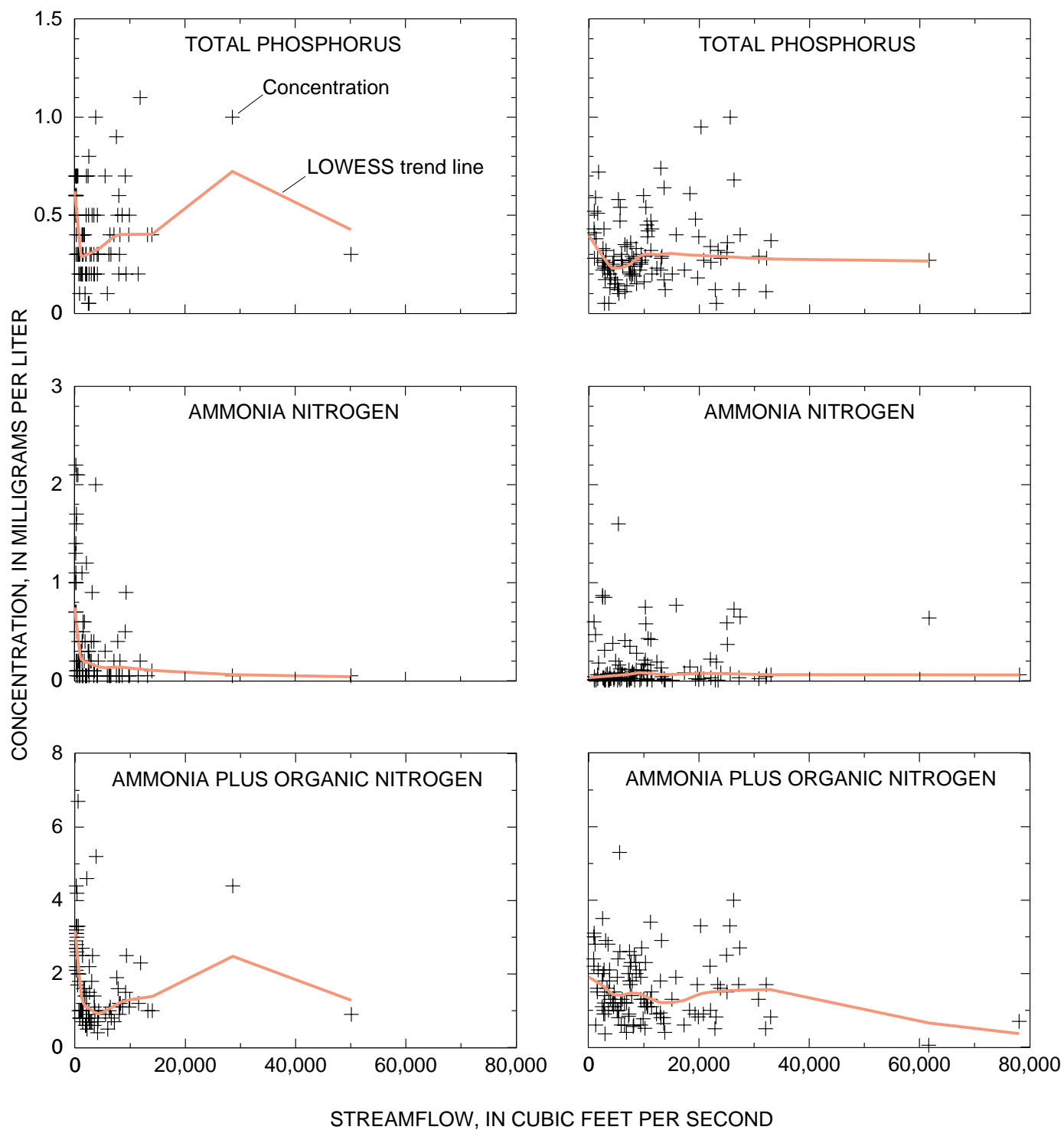
Typically, there is variation in streamflows with the seasons that can affect the transport and fate of nutrients. Streamflows often are higher during the spring because of the runoff from snowmelt and spring rains, high water tables causing increased base flows, and low rates of evapotranspiration during these months. During the late winter and early spring, the soils are still partially frozen or water saturated, and rainfall typically runs off. In contrast, streamflow is lowest during the late summer and fall (August, September, and October) because of less precipitation, less runoff, and a lower water table causing low base flow during these months. The soils are usually dryer, and evapotranspiration is higher during late summer and early fall.

Boxplots for nitrate concentration data considered typical for each season are shown in figure 17 (p. 38) for selected sites (Cedar River at Cedar Falls, Cedar River near Palo, Iowa River at Wapello, and Skunk River at Augusta). Generally, median concentrations of nitrate were highest in the spring (April–June), decreased in summer, and increased again in late fall to early winter. Median nitrate concentrations were approximately 6.0 mg/L for the spring, decreased to 2.0 to 4.0 mg/L during the summer, and increased to approximately 4.0 to 5.0 mg/L during the fall through winter.

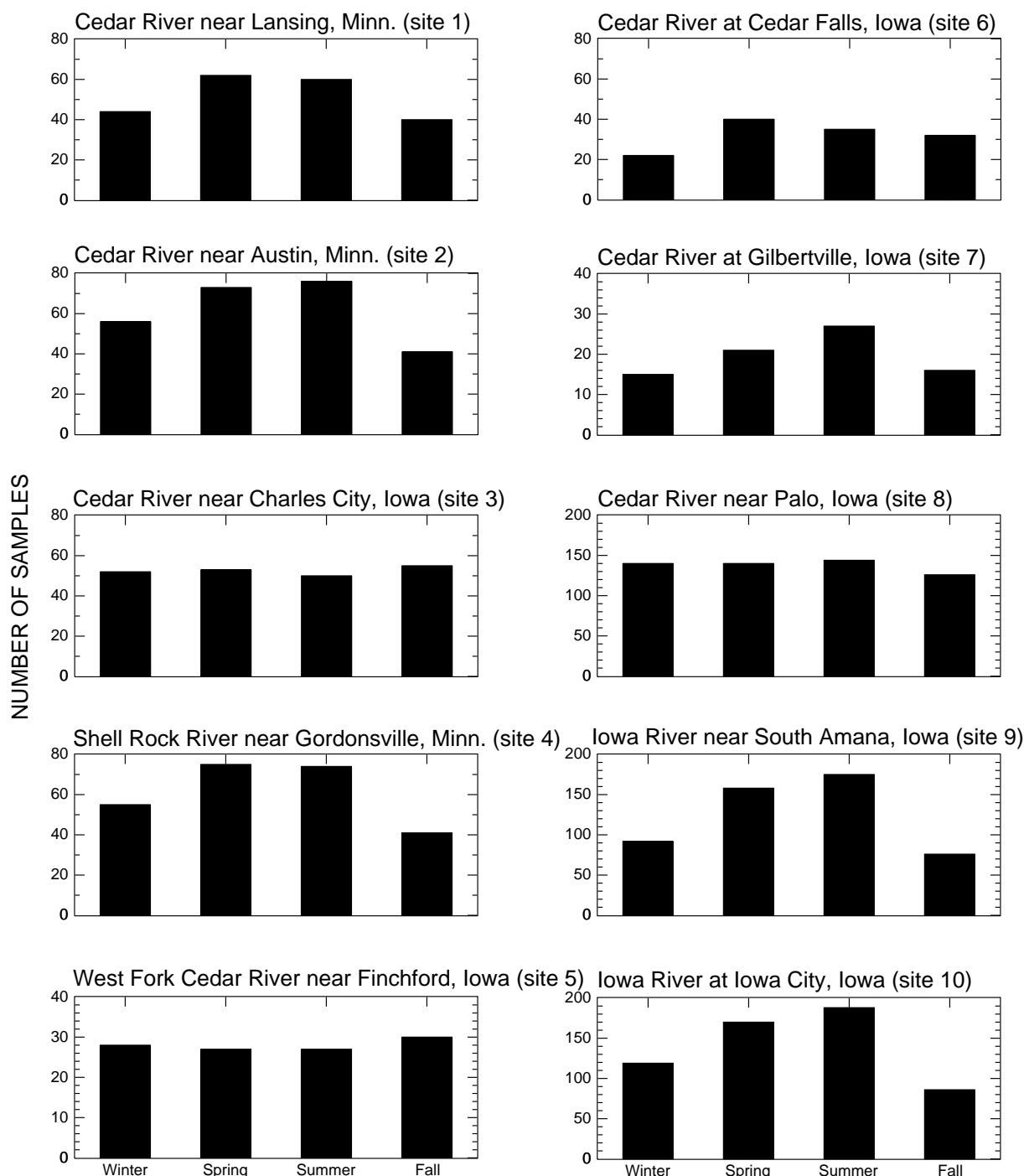
The fall and winter nitrate concentrations usually were higher than the summer concentrations but generally not as high as spring concentrations.

Iowa River at Columbus Junction, Iowa  
(site 12)

Iowa River at Wapello, Iowa  
(site 13)



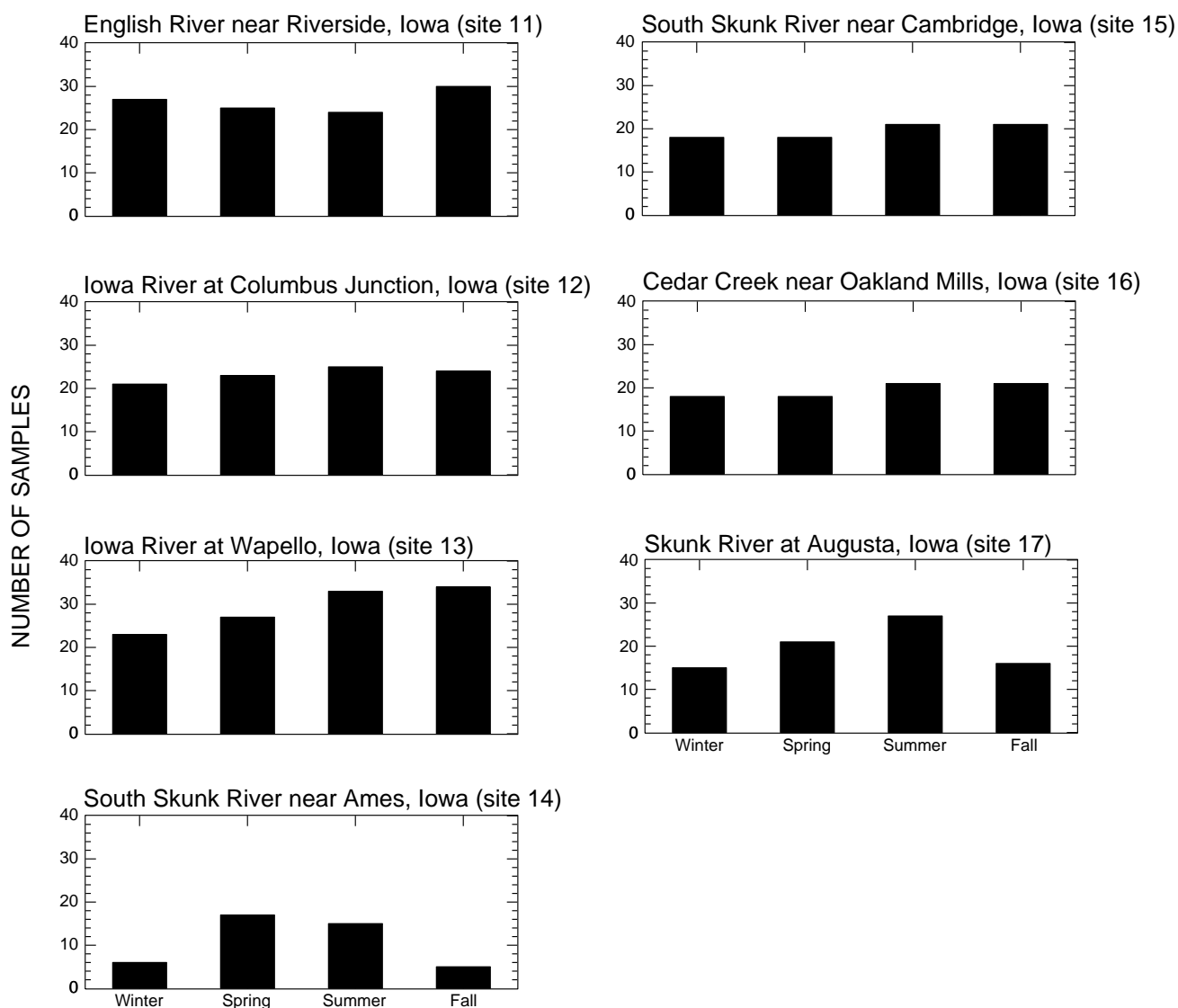
**Figure 15.** Relations of total phosphorus, ammonia, and ammonia plus organic nitrogen concentrations to streamflow, indicating possible point-source contamination at Columbus Junction and Wapello, Iowa, surface-water-quality monitoring sites, 1970–95.



**Figure 16.** Number of nitrate samples collected by season at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.

Other monitoring sites followed this basic trend. The highest concentrations of nitrate occurred during the spring with somewhat elevated concentrations in the late fall and early winter. This pattern is consistent with seasonal patterns observed in the Midwestern United States (Goolsby and Battaglin, 1993, p. 17).

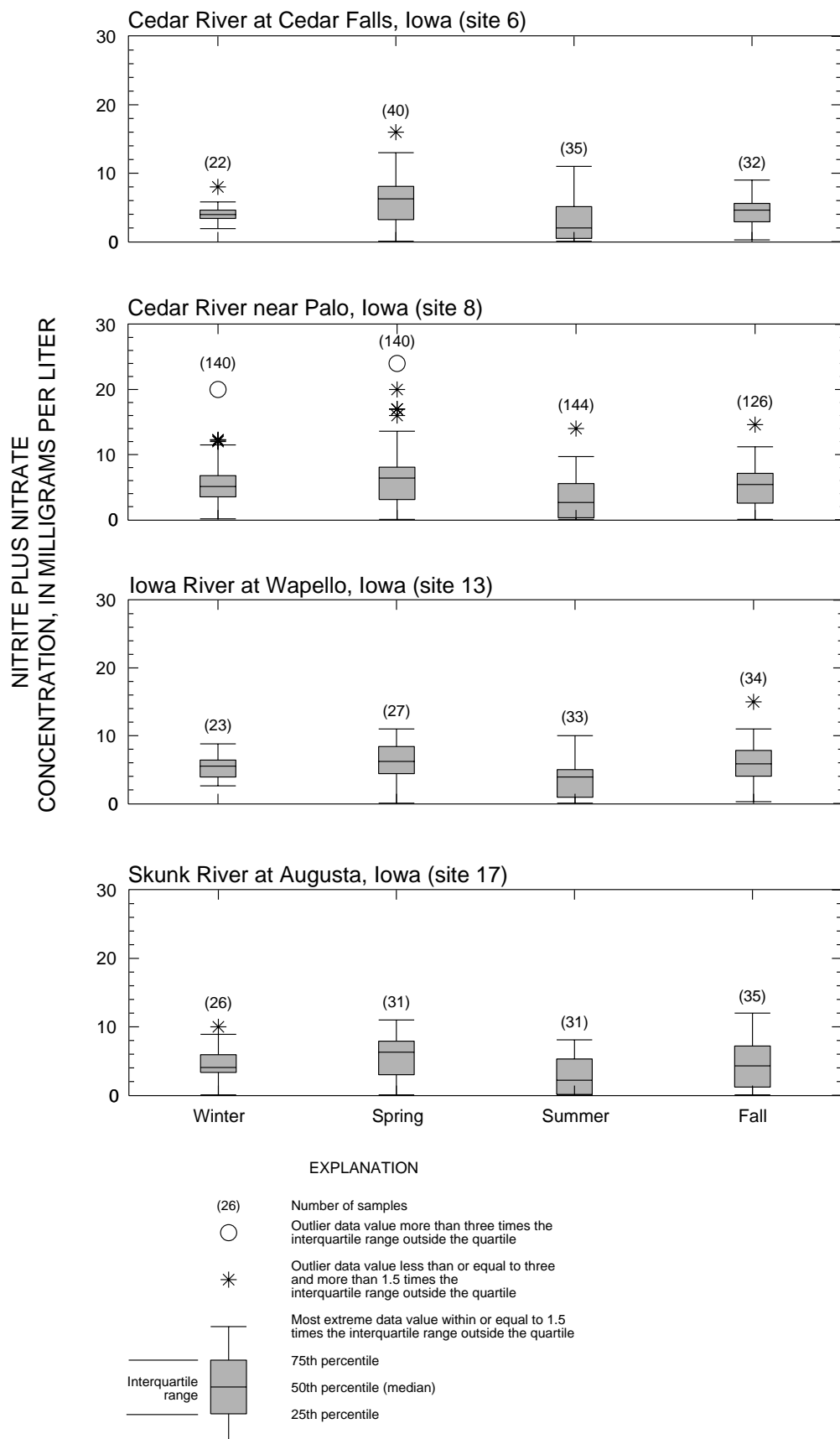
Basin size seemed to have little effect on the seasonal aspects of nitrate concentrations because this pattern was observed in data both from smaller and larger basins. Fertilizers often are applied to fields prior to the growing season (late fall and early spring). In Minnesota, farmers often spread manure from



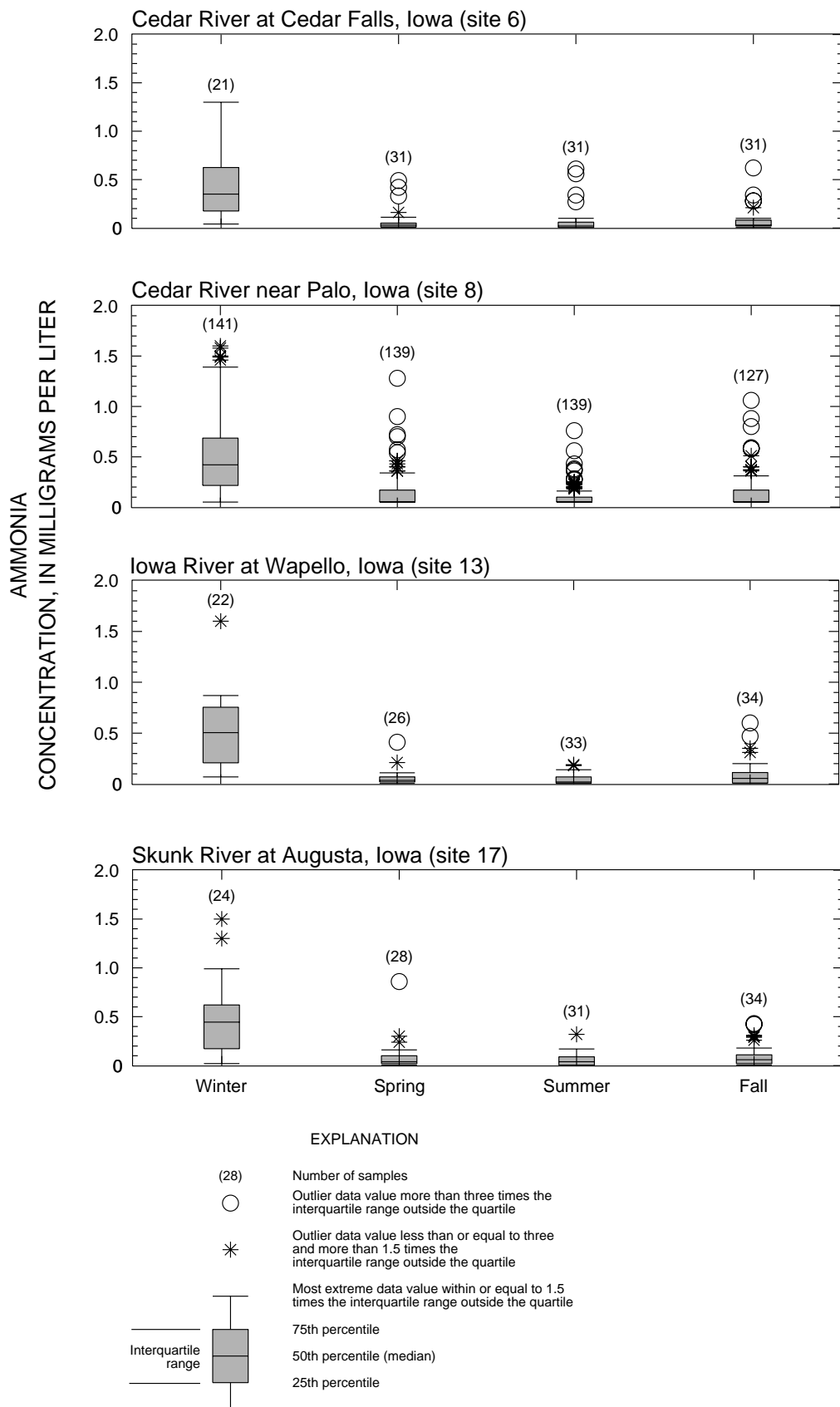
**Figure 16.** Number of nitrate samples collected by season at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95—Continued.

dairy cow operations on fields throughout the winter months (James Fallon, U.S. Geological Survey, oral commun., 1998). Nitrate is produced by nitrification of ammonia, fertilizers, and animal wastes in soil. Nitrate may accumulate in soil because of a lack of uptake by dormant vegetation (Likens and others, 1977, p. 48). The high spring nitrate concentrations in streams probably results from the transport of nitrate that accumulated in the soil and from runoff events, particularly after the spring application of fertilizer. The lack of biological activity of algae and other plants in streams during the winter and early spring could result in higher nitrate concentrations. Bonn and others (1996) attributed high nitrate concentrations in

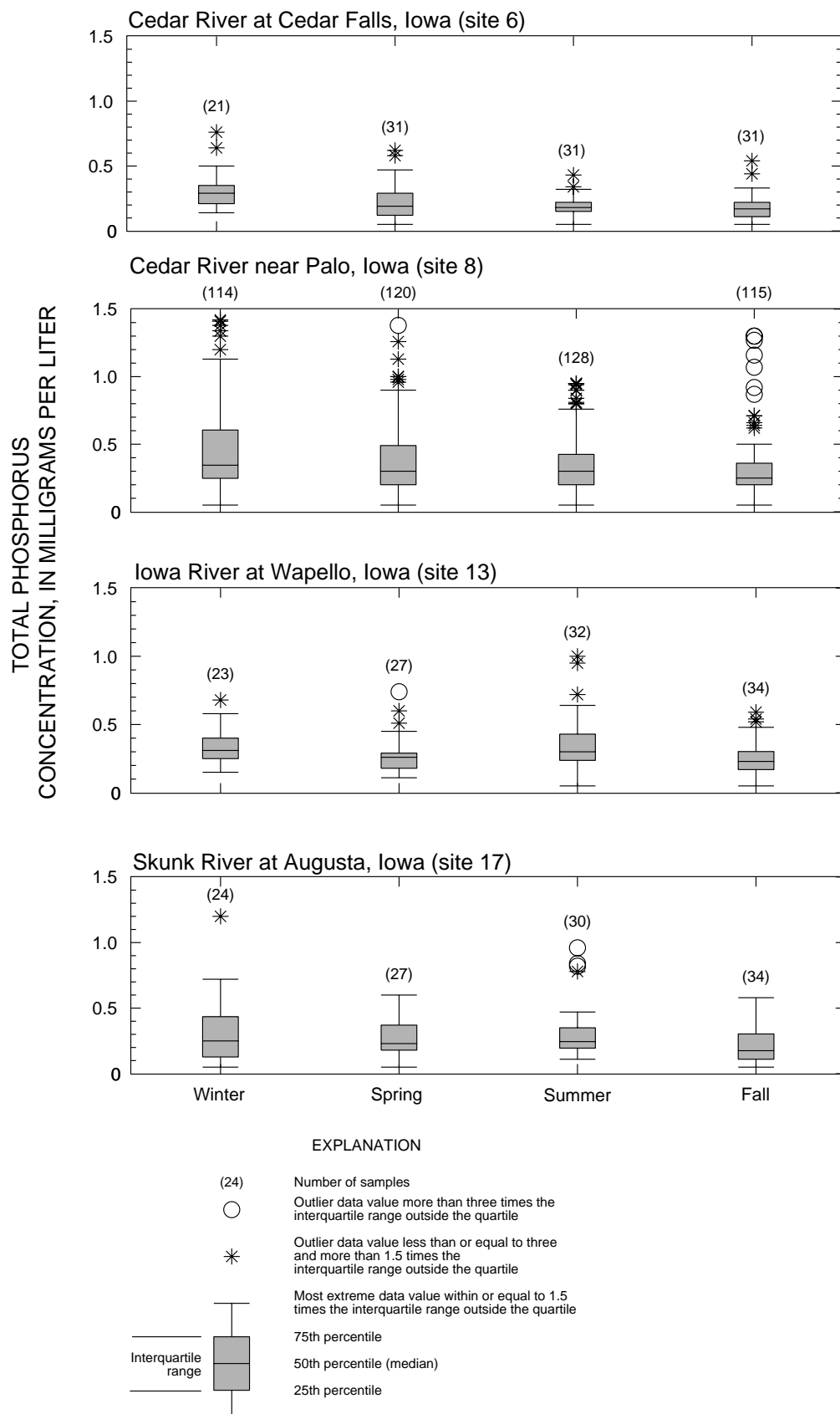
the winter to a combination of leaching of nitrate from soils by winter rains and less nitrate uptake by algae in streams. The uptake of nitrate by terrestrial plants and aquatic vegetation in streams would result in lower nitrate concentrations in the late summer and early fall. In addition, application of fertilizers during this time period would be less than during spring or even late fall. Little transport of nitrate to surface water during the late summer and early fall occurs because fertilizer has not been applied recently, uptake of nitrate by terrestrial plants and aquatic vegetation is greater, and there is less runoff during this time of year due to high evapotranspiration and low precipitation.



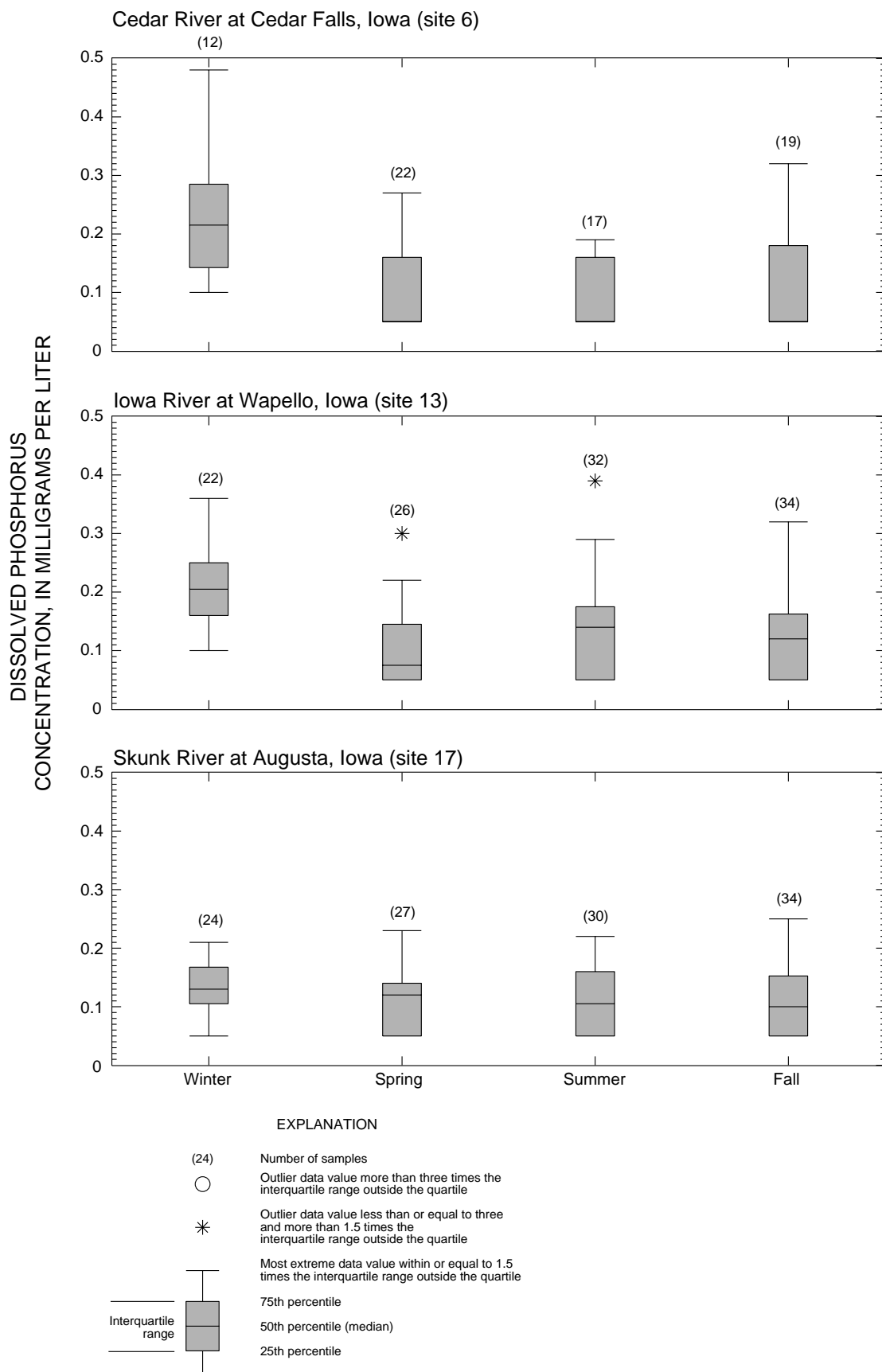
**Figure 17.** Nitrite plus nitrate concentrations by season at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



**Figure 18.** Ammonia concentration by season at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



**Figure 19.** Total phosphorus concentration by season at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



**Figure 20.** Dissolved phosphorus concentrations by season at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.

Median ammonia concentrations generally were highest during the winter (January–March) for all the monitoring sites. The boxplots shown in figure 18 (p. 39) were selected as representative of the monitoring sites. Typically, the ammonia concentrations begin to increase in December, and the highest median ammonia concentrations usually occur in February. The higher ammonia concentrations detected during the winter months probably are due to the decreased uptake of ammonia by algae and other aquatic vegetation. The colder river temperatures would decrease the volatilization of ammonia and reduce the biochemical conversion of ammonia to nitrate. Several water-quality surveys conducted by UHL in the 1970's found elevated ammonia levels downstream from wastewater discharges in the Cedar, Iowa, and Skunk River Basins during winter streamflow conditions (University of Hygienic Laboratory, 1976a; 1976b; 1977a; 1977b, 1978). Reduced assimilation by algae and aquatic vegetation and low rates of oxidation of ammonia at colder temperatures were identified as factors in cases where high ammonia concentrations persisted for many miles downstream from point sources.

The median concentrations of ammonia typically are the lowest from April to September (growing season). The uptake of ammonia by aquatic plants would decrease the ammonia concentrations in the stream during the growing season. In addition, ammonia concentrations could decrease during the summer and fall because of increased conversion of ammonia to nitrate and increased volatilization of ammonia with warmer temperatures (Crumpton and Isenhardt, 1987).

The boxplots for the concentrations of total phosphorus did not show the same strong seasonal pattern as did nitrate. Phosphorus is transported more often with sediment and, thus, may be more variable than nitrate. In addition, seasonal trends for nitrate may be linked more closely to aquatic plant growth than phosphorus. If phosphorus is not a limiting nutrient (when compared to nitrate) in streams in the study unit, then little variation of phosphorus concentrations will occur with aquatic plant growth during the growing season. The strong link between nitrate and the biological uptake of aquatic plants in the summer may result in a more pronounced seasonal pattern for nitrate than for phosphorus concentrations.

In general, the median concentrations of total phosphorus varied less than 0.1 mg/L between seasons. Figure 19 (p. 40) shows selected boxplots for seasonal total phosphorus concentrations that are representative of the majority of the monitoring sites. Seasonal trends in the median total phosphorus concentrations were almost nonexistent (fig. 19). Total phosphorus median concentrations were slightly higher (by approximately 0.1 mg/L) during the winter season compared to the other seasons for Cedar River at Cedar Falls (site 6), Cedar River near Palo (site 8), and Skunk River at Augusta (site 17) (fig. 19). Other monitoring sites that are not shown, such as Cedar River near Austin, Minnesota (site 2), Shell Rock River near Gordonsville, Minnesota (site 4), Cedar River at Gilbertville (site 7), and Iowa River at Columbus Junction (site 12), followed this trend with slightly higher median concentrations (0.1 to 0.2 mg/L) during the winter.

The slightly higher total phosphorus concentrations during the winter at the majority of the monitoring sites may indicate a lack of terrestrial and aquatic biological activity in the winter. Generally, dissolved orthophosphate and phosphorus are more readily used by aquatic plants. Slightly higher concentrations of these dissolved species would be expected in the winter when there would be a decreased uptake by aquatic plants. Long-term dissolved phosphorus data for seasonal analysis were available for only three sites [Cedar River at Cedar Falls (site 6), Iowa River at Wapello (site 13), and Skunk River at Augusta (site 17)], and data for these sites indicate higher median dissolved phosphorus concentrations during the winter months before biological activity begins in the early spring (fig. 20, p. 41). Some of the higher median phosphorus concentrations could be caused by wastewater-treatment-plant effluent that is not as well diluted during winter low streamflows. In previous studies, elevated levels of dissolved phosphorus were found during winter flow conditions in the Cedar and Iowa Rivers downstream from wastewater discharge points (University of Iowa Hygienic Laboratory, 1976b; 1977a). Virtually all of the phosphorus was in the soluble phase. Three monitoring sites—Cedar River at Gilbertville (site 7), Iowa River at Columbus Junction (site 12), and Skunk River near Cambridge (site 15)—show greater phosphorus concentrations at the lowest streamflows (1,500 ft<sup>3</sup>/s or less), perhaps indicating point-source effects (negative trend slope, fig. 13, p. 31).

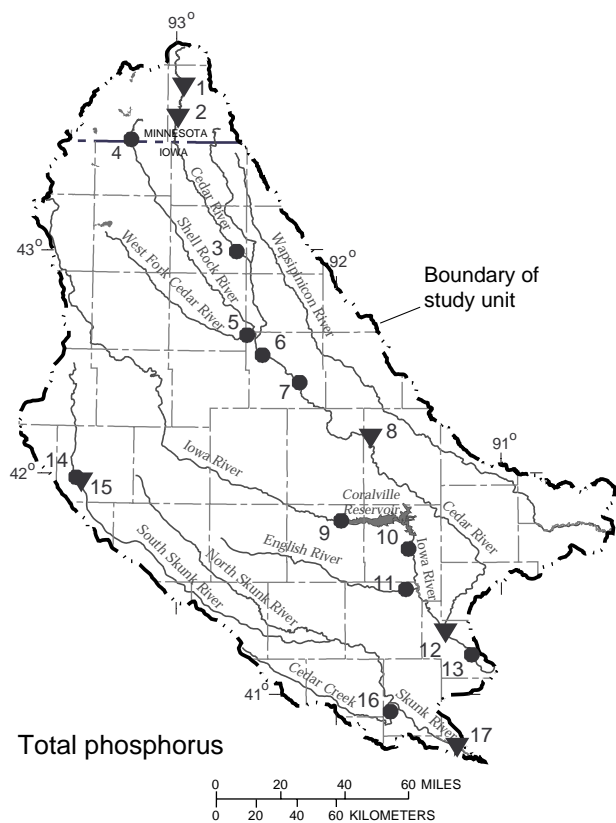
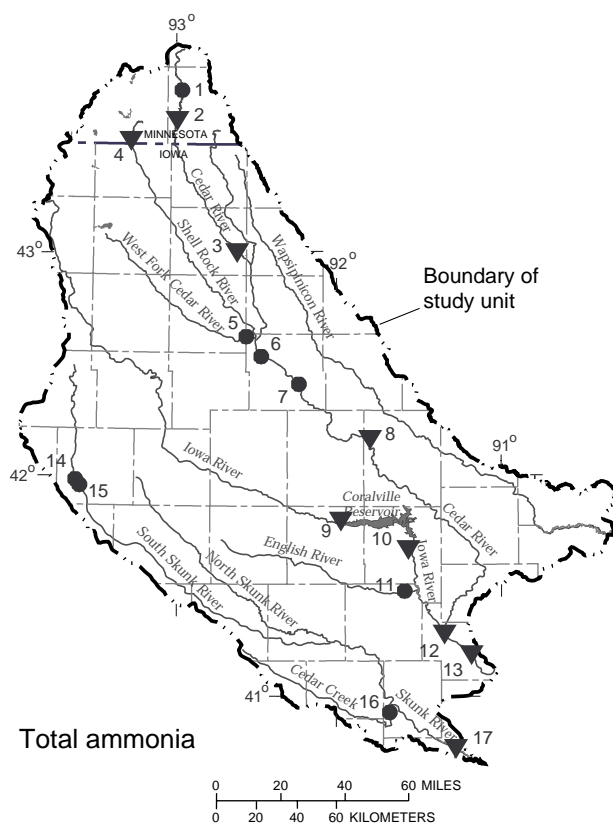
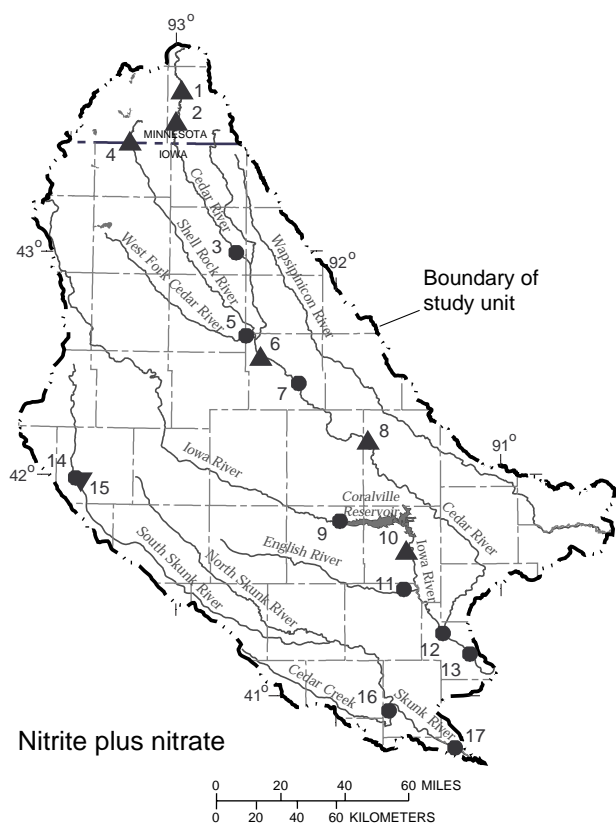
## Time Trends in Concentrations and Loads

Time trends in nutrient concentrations and loads can indicate long-term improvement or deterioration in stream quality and may be caused by various conditions within a drainage basin. Water-quality data compiled at the selected monitoring sites in the EIWA study unit for this report were examined to determine if concentrations and loads of nutrients appeared to be increasing or decreasing over time. Trend analyses discussed in this section are considered exploratory because the rigorous statistical analysis needed to confirm trends and the causes of trends (McLeod and others, 1991, p. 174) was beyond the scope of this study.

Results of the seasonal Kendall tau tests for trend analysis of concentrations are presented in tables 5–7. Results that are significant (p-value less than or equal to 0.05) are highlighted in bold type in the tables. The magnitude of the Kendall slope estimate (trend slope) of the relation of concentration to time trend are listed when the p-value is less than or equal to 0.05. The trend slopes are listed in milligrams per liter per year. The results of the seasonal Kendall tau tests for instantaneous loads (concentration of constituent multiplied by the streamflow at the time of sample collection) are shown in tables 8–10. Instantaneous loads indicate how much of a particular constituent a stream is transporting at a particular point in time. There were some apparent anomalies in the instantaneous load data for all nutrient species between site 12 (Iowa River at Columbus Junction) and site 13 (Iowa River at Wapello) that were related to the streamflow data for these two sites. The Iowa River at the Columbus Junction monitoring site (site 12) is located at the confluence of the Iowa River and Cedar Rivers (fig. 1, p. 4); however, these rivers are not well mixed at the point of confluence, and streamflow data from the Iowa River at site 12 in the STORET data sets were for the Iowa River rather than the combined streamflow of the Iowa and Cedar Rivers. In contrast, at site 13 (Iowa River at Wapello), which is about 13 mi downstream from the confluence of the Iowa and Cedar Rivers (fig. 1, p. 4), the streamflow data in the STORET data sets were for the combined streamflow of the Iowa and Cedar Rivers. Thus, site 13 (Iowa River at Wapello) will have much larger streamflow and, therefore, higher instantaneous loads (for similar concentrations of constituents) than site 12 (Iowa River at Columbus Junction). When comparing the instantaneous loads at sites 12 and 13, site 12 is most representative of the Iowa River Basin, whereas site 13 represents instantaneous loads

from the Iowa and the Cedar River Basins combined. Figure 21 summarizes the results of the seasonal Kendall tau tests for ammonia, nitrate, and total phosphorus concentrations for the monitoring sites.

Nitrate concentrations have increased during 1970–95 in the Cedar River near Lansing, Minnesota (site 1), Cedar River near Austin, Minnesota (site 2), Shell Rock River near Gordonsville, Minnesota (site 4), Cedar River at Cedar Falls (site 6), Cedar River near Palo (site 8), and Iowa River at Iowa City (site 10) (fig. 21, p. 44 and table 5, p. 47). The South Skunk River near Cambridge (site 15) shows a decreasing nitrate concentration (fig. 21, p. 44 and table 5, p. 47); however, nitrate concentrations are generally higher (median 8.8 mg/L) at site 15 than at the other monitoring sites (medians 2.2 to 5.6 mg/L) (table 5, p. 47). The higher nitrate concentration near Cambridge probably reflects the nitrification of ammonia that occurred in an upstream wastewater-treatment plant instead of the river. A new wastewater facility was completed in 1989. Prior to the operation of the new facility, high ammonia-nitrogen concentrations were known to occur in the South Skunk below the wastewater-treatment plant, particularly during low-flow conditions (University of Iowa Hygienic Laboratory, 1976a). The nitrification of ammonia in wastewater-treatment plants along the Cedar River also may be a source of increased nitrate for many of the monitoring sites along the Cedar River. In addition, use of nitrogen applied as fertilizer increased during 1960–80 (fig. 22) (Alexander and Smith, 1990; Kerie Hitt, U.S. Geological Survey, written commun., 1994). Figure 22 shows a large, steady increase in nitrogen fertilizer use starting in the early 1960's and continuing through the late 1970's. Nitrate concentrations in EIWA study unit streams also probably increased during this time period. Monitoring locations with data that date back to the early to mid-1970's, such as Cedar River near Lansing, Minnesota (site 1), and Cedar River near Palo (site 8), appear to show increasing nitrate concentrations with time (fig. 23, p. 46 and table 5, p. 47). However, there was a leveling off of nitrogen use during 1980–90, when an average of about 413,000 tons (375,000 metric tons) of nitrogen were applied annually in the EIWA study unit (fig. 22). The precipitous decrease in nitrogen and phosphorus application in 1983 (fig. 22) may reflect corn-acreage reductions in that year resulting from the Payment-in-Kind (PIK) Federal farm program. The PIK program compensated farmers for removing corn acreage from production.

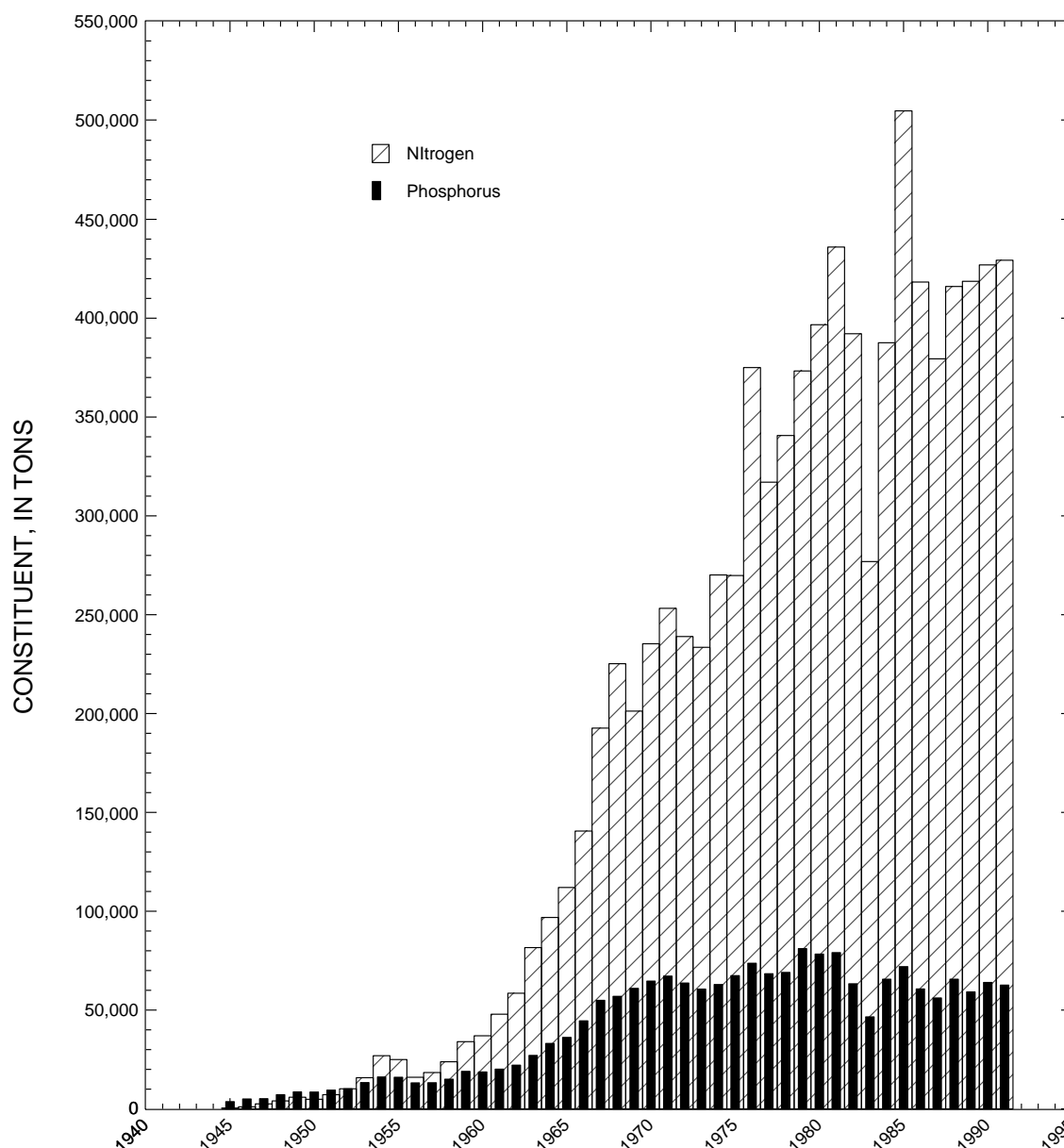


## EXPLANATION

### MONITORING SITES AND NUMBERS

- ▲ 2 Upward trend at site
- ▼ 8 Downward trend at site
- 6 No trend indicated at site

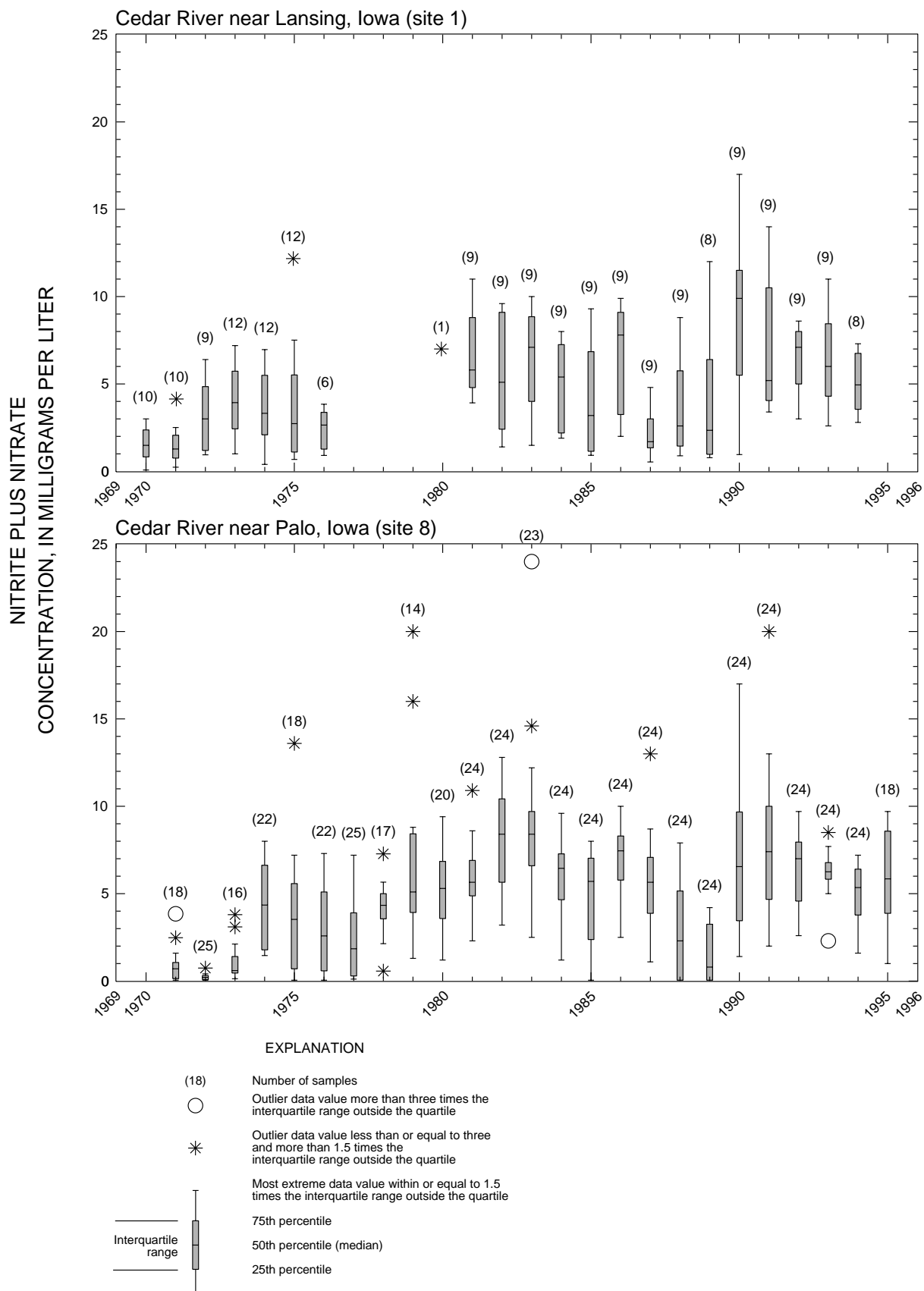
**Figure 21.** Maps showing time trends in nutrient concentrations at selected surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95.



**Figure 22.** Nitrogen and phosphorus fertilizer use in the Eastern Iowa Basins, 1945–91 (modified from Alexander and Smith, 1990, and Kerie Hitt, U.S. Geological Survey, written commun., 1994).

The instantaneous nitrate loads (table 8, p. 51) generally show increases at several sites—Cedar River near Austin, Minnesota (site 2), Cedar River at Cedar Falls, Iowa (site 6), Cedar River at Gilbertville, Iowa (site 7), Iowa River at Iowa City, Iowa (site 10), and Iowa River at Columbus Junction, Iowa (site 12). These increases in loads, like concentrations, may be related to increased fertilizer use or nitrification by wastewater-treatment plants. The Cedar River near Palo, Iowa (site 8), was the one monitoring site that showed a statistically significant decrease in nitrate

loads. The reason for this decrease in nitrate loads was unknown. In addition, there was a slight decrease in median nitrate loads from 30.2 ton/d to 28.4 ton/d (table 8, p. 51) moving downstream from site 6 (Cedar River at Cedar Falls, Iowa) to site 7 (Cedar River at Gilbertville, Iowa) on the Cedar River, respectively. The cause for this nitrate “sink” is unknown but may be due to instream processing of nitrate (for example, by uptake by aquatic plants). Another possibility is the closing of some industrial plants (and possible point-source inputs) in Waterloo, Iowa, over time, although



**Figure 23.** Nitrite plus nitrate concentrations by year at selected surface-water-quality monitoring sites in the Eastern Iowa Basins.

**Table 5.** Summary of seasonal Kendall trend analysis of nitrite plus nitrate nitrogen concentrations at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

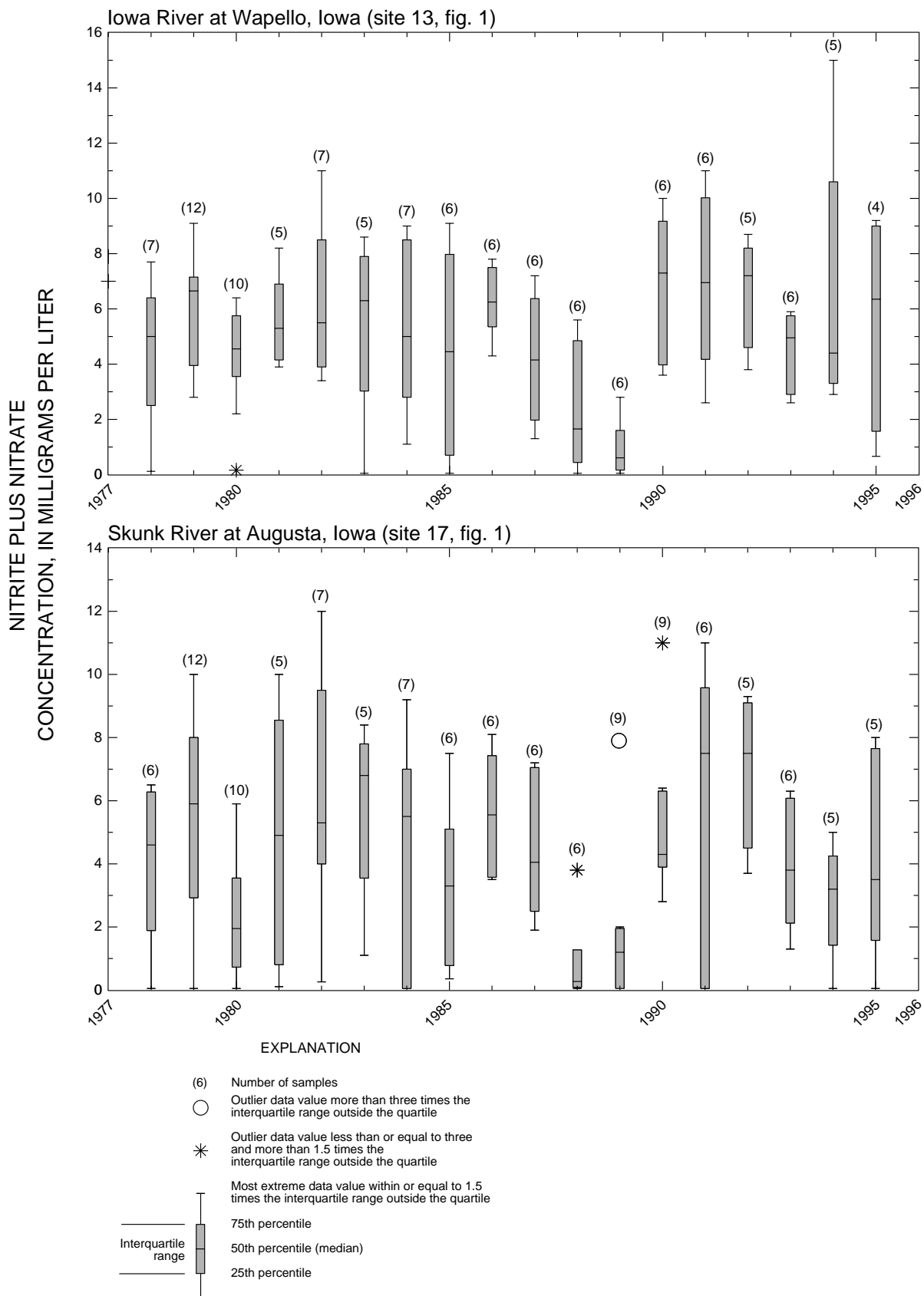
[mg/L as N, milligrams per liter as nitrogen; (mg/L)/yr, milligrams per liter per year; **results in bold** are significant with p-values less than or equal to 0.05; nt, no trend indicated; <, less than]

Monitoring site number (fig. 1)	Site name	Median nitrite plus nitrate nitrogen concentration (mg/L) as N	Kendall tau	p-value	Trend slope [(mg/L)/yr]
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	4.0	<b>0.33</b>	<b>&lt;0.0001</b>	<b>+0.1451</b>
2	Cedar River near Austin, Minnesota	3.9	<b>.29</b>	<b>.0001</b>	<b>+.0938</b>
3	Cedar River near Charles City, Iowa	5.6	.06	.4953	nt
4	Shell Rock River near Gordonsville, Minnesota	2.2	<b>.40</b>	<b>&lt;.0001</b>	<b>+.1682</b>
5	West Fork Cedar River near Finchford, Iowa	5.4	.14	.3134	nt
6	Cedar River at Cedar Falls, Iowa	4.1	<b>.22</b>	<b>.0241</b>	<b>+.0944</b>
7	Cedar River at Gilbertville, Iowa	4.1	.23	.1209	nt
8	Cedar River near Palo, Iowa	5.0	<b>.33</b>	<b>&lt;.0001</b>	<b>+.1853</b>
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	4.9	.06	.4579	nt
10	Iowa River at Iowa City, Iowa	4.2	<b>.22</b>	<b>.0028</b>	<b>+.1107</b>
11	English River near Riverside, Iowa	4.3	–.10	.4693	nt
12	Iowa River at Columbus Junction, Iowa	4.7	.27	.0739	nt
13	Iowa River at Wapello, Iowa	5.3	–.03	.7718	nt
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	2.4	.33	1.0000	nt
15	South Skunk River near Cambridge, Iowa	8.8	<b>–.56</b>	<b>.0011</b>	<b>–1.354</b>
16	Cedar Creek near Oakland Mills, Iowa	3.7	.03	.8840	nt
17	Skunk River at Augusta, Iowa	4.1	–.13	.1246	nt

these effects are unknown. Also, the period of record in the original data sets for sites 6 and 7 was slightly different (table 2, p. 12). Site 6 had data from approximately 1975–79 and also 1984–95, whereas site 7 had data from 1975–81 and 1984–85. A similar reduction in median nitrate loads (table 8, p. 51), from 16.9 ton/d to 15.7 ton/d, was apparent on the Iowa River from site 9 (Iowa River near South Amana, Iowa) to site 10 (Iowa River at Iowa City, Iowa), respectively. Coralville Reservoir is between sites 9 and 10 on the Iowa River. One likely explanation is that the reservoir is acting as a nitrate “sink” that decreases nitrate loads between the upstream site 9 and the downstream site 10. One apparent anomaly in table 8 (p. 51) is a large increase in nitrate load (26.7 to 147.4 tons/d) between site 12 (Iowa River at Columbus Junction) and site 13 (Iowa River at Wapello); this increase is related to streamflow data for these two sites. As stated earlier, the instantaneous discharge data in the STORET data sets for site 13 includes the combined

Cedar and Iowa River streamflows, whereas instantaneous streamflow data for site 12 only are for the Iowa River. Therefore, the combined Iowa and Cedar River streamflows at site 13 result in a larger nitrate load (147.4 ton/d) when compared to site 12.

A study-unit-wide increase in nitrate concentrations was apparent at all the monitoring sites following the 1988–89 drought. Major flooding occurred during June 1990 on most rivers and streams in east-central Iowa as the drought ended (O’Connell and others, 1990). Nitrate concentrations in streams that were lower than normal during the drought increased in the spring and summer of 1990. The Skunk River at Augusta (site 17) and Iowa River at Wapello (site 13) are two monitoring sites selected to show the increased nitrate following the 1988–89 drought (fig. 24). The increased nitrate concentrations have been attributed to the leaching and transport of nitrate that had accumulated in the soil during the drought of 1988–89 (Lucey and Goolsby, 1993).



**Figure 24.** Nitrite plus nitrate concentrations by year showing increased concentrations in 1990 following the 1988–89 drought at two representative surface-water-quality monitoring sites in the Eastern Iowa Basins study unit.

Total ammonia concentrations decreased at several monitoring sites during 1970–95: Cedar River near Austin, Minnesota (site 2), Cedar River near Charles City, Iowa (site 3), Shell Rock River near Gordonsville, Minnesota (site 4), Cedar River at Palo, Iowa (site 8), Iowa River near South Amana (site 9), Iowa River at Iowa City (site 10), Iowa River at Columbus Junction (site 12), Iowa River at Wapello (site 13), and Skunk River at Augusta (site 17) (fig. 21, p. 44 and table 6, p. 49). Decreasing ammonia concentration trends for these monitoring sites most likely reflect improvements to the wastewater-treatment plants implemented in the 1980's. Several water-quality surveys conducted in the 1970's by UHL documented elevated ammonia concentrations downstream from wastewater discharges in the Cedar, Iowa, and Skunk River Basins (University of Iowa Hygienic Laboratory, 1970, 1971, 1976a, 1976b, 1977a, 1977b, 1978). The most apparent trends in

decreasing ammonia concentrations were found at monitoring sites located immediately downstream from major point sources, such as Cedar River near Austin, Minnesota (site 2), Shell Rock River near Gordonsville (site 4) (downstream from Albert Lea, Minnesota), and Iowa River at Columbus Junction (site 12) (includes the meat-packing plant effluent). The trend slopes at these sites ranged from –0.013 to –0.038, and the median concentrations ranged from 0.20 to 0.59 mg/L (table 6). The largest decreases in ammonia concentrations would be expected immediately downstream after improvements were made to wastewater-treatment plants.

The instantaneous ammonia loads decreased for the Cedar River near Austin (site 2) and the Cedar River near Charles City (site 3), suggesting point-source decreases upstream from these monitoring sites (table 9, p. 52). The Cedar River near Palo (site 8) also had a negative trend slope for ammonia loads (table 9,

**Table 6.** Summary of seasonal Kendall trend analysis of ammonia nitrogen concentrations at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[mg/L as N, milligrams per liter as nitrogen; (mg/L)/yr, milligrams per liter per year; **results in bold** are significant with p-values less than or equal to 0.05; nt, no trend indicated; <, less than]

Monitoring site number (fig. 1)	Site name	Median ammonia nitrogen concentration (mg/L) as N	Kendall tau	p-value	Trend slope [(mg/L)/yr]
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	0.14	–0.12	0.1136	nt
2	Cedar River near Austin, Minnesota	.59	<b>–.37</b>	<b>&lt;.0001</b>	<b>–0.0305</b>
3	Cedar River near Charles City, Iowa	<.10	<b>–.26</b>	<b>.0001</b>	<b>–.00001</b>
4	Shell Rock River near Gordonsville, Minnesota	.29	<b>–.20</b>	<b>.0064</b>	<b>–.0132</b>
5	West Fork Cedar River near Finchford, Iowa	<.10	–.02	.8357	nt
6	Cedar River at Cedar Falls, Iowa	.04	–.18	.0572	nt
7	Cedar River at Gilbertville, Iowa	.06	–.17	.2505	nt
8	Cedar River near Palo, Iowa	<.10	<b>–.48</b>	<b>&lt;.0001</b>	<b>–.0062</b>
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	<.10	<b>–.18</b>	<b>.0221</b>	<b>–.00001</b>
10	Iowa River at Iowa City, Iowa	.13	<b>–.22</b>	<b>.0015</b>	<b>–.0035</b>
11	English River near Riverside, Iowa	.08	.17	.1384	nt
12	Iowa River at Columbus Junction, Iowa	.20	<b>–.51</b>	<b>.0001</b>	<b>–.0375</b>
13	Iowa River at Wapello, Iowa	.06	<b>–.19</b>	<b>.0282</b>	<b>–.0027</b>
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	.77	.33	1.0000	nt
15	South Skunk River near Cambridge, Iowa	<.10	–.04	.7585	nt
16	Cedar Creek near Oakland Mills, Iowa	<.10	.19	.0562	nt
17	Skunk River at Augusta, Iowa	.06	<b>–.18</b>	<b>.0362</b>	<b>–.0029</b>

**Table 7.** Summary of seasonal Kendall trend analysis of total phosphorus concentrations at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[mg/L as P, milligrams per liter as phosphorus; (mg/L)/yr, milligrams per liter per year; **results in bold** are significant with p-values less than or equal to 0.05; nt, no trend indicated; <, less than; --, no data or not enough data to conduct test]

Monitoring site number (fig. 1)	Site name	Median total phosphorus concentration (mg/L) as P	Kendall tau	p-value	Trend slope [(mg/L)/yr]
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	0.17	<b>−0.37</b>	<b>&lt;0.0001</b>	<b>−0.0052</b>
2	Cedar River near Austin, Minnesota	.53	<b>−.35</b>	<b>&lt;.0001</b>	<b>−.0178</b>
3	Cedar River near Charles City, Iowa	.22	−.08	.3369	nt
4	Shell Rock River near Gordonsville, Minnesota	.66	−.09	.2239	nt
5	West Fork Cedar River near Finchford, Iowa	.12	.05	.7292	nt
6	Cedar River at Cedar Falls, Iowa	.19	0	1.0000	nt
7	Cedar River at Gilbertville, Iowa	.31	−.07	.6654	nt
8	Cedar River near Palo, Iowa	.30	<b>−.27</b>	<b>.0005</b>	<b>−.0074</b>
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	--	--	--	nt
10	Iowa River at Iowa City, Iowa	<.10	.24	.0693	nt
11	English River near Riverside, Iowa	.20	.07	.6597	nt
12	Iowa River at Columbus Junction, Iowa	.40	<b>−.35</b>	<b>.0165</b>	<b>−.0333</b>
13	Iowa River at Wapello, Iowa	.27	−.11	.1944	nt
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	.37	.33	1.0000	nt
15	South Skunk River near Cambridge, Iowa	.40	<b>−.51</b>	<b>.0022</b>	<b>−.1000</b>
16	Cedar Creek near Oakland Mills, Iowa	.20	.04	.7771	nt
17	Skunk River at Augusta, Iowa	.23	<b>−.20</b>	<b>.0228</b>	<b>−.0050</b>

p. 52) that would suggest decreases in ammonia across a large portion of the basin, as the site is many miles downstream from possible point-source effects. The English River near Riverside site (site 11) and Cedar Creek near Oakland Mills site (site 16) had increasing instantaneous ammonia loads, but the magnitude of their trend slopes was small—0.0081 and 0.0032 (mg/L)/yr, respectively (table 9, p. 52). These monitoring sites are both in relatively small, rural river basins. However, several new livestock facilities began operation in the 1990’s in each of these river basins (fig. 4, p. 10). It is unknown if the waste from livestock facilities could be a source of the slight increase in instantaneous ammonia loads observed at these sites.

Total phosphorus showed a trend of decreasing concentrations at several monitoring sites during 1970–95. Cedar River near Lansing, Minnesota (site 1), Cedar River near Austin, Minnesota (site 2), Cedar

River near Palo (site 8), Iowa River at Columbus Junction (site 12), South Skunk River near Cambridge (site 15), and Skunk River at Augusta (site 17) had downward trends in total phosphorus concentrations (fig. 21, p. 44 and table 7, p. 50). Data from the instantaneous total phosphorus loads (table 10) also show negative trend slopes for Cedar River near Austin, Minnesota (site 2), and Cedar River near Palo (site 8) sites (table 10, p. 53). This may be related to improvements made in the treatment processes of wastewater-treatment plants combined with a gradual decline since the early 1980’s in phosphorus fertilizer application in the study unit (fig. 22, p. 45).

Instantaneous total phosphorus loads for Cedar River at Cedar Falls (site 6), Cedar River at Gilbertville (site 7), and Cedar Creek near Oakland Mills (site 16) show upward trends (table 10, p. 53). Cedar River at Cedar Falls (site 6) has relatively low

median total phosphorus concentrations (0.19 mg/L) compared to Cedar River at Gilbertville (table 7, site 7) (0.31 mg/L). Explanations for these trends are unknown. Point-source inputs from Waterloo, Iowa, which is upstream from Gilbertville, may be contributing to the increasing load trend at Gilbertville or may represent increases from nonpoint sources over time. Cedar Creek near Oakland Mills (site 16) drains a smaller, rural watershed, and the cause of the slight increase in total phosphorus loads [0.0056 (mg/L)/yr] is unknown, but could possibly be related to changes in livestock production and distribution. Permitted hog confinement facilities in the Cedar Creek watershed were begun in the 1990's, but their impact on phosphorus loads has not been studied. In addition, study on phosphorus becoming "overloaded" in agricultural soils from years of fertilizer application (chemical and

manure) may be useful in the EIWA study unit. High soil phosphorus can be an important factor in phosphorus transport to streams (Gburek and Sharpley, 1998; Schepers and Francis, 1998). Additional research would be important in understanding possible explanations for increasing total phosphorus trends observed in the study unit.

## Pesticides

The transport and fate of pesticides in the hydrologic environment strongly depend on the water solubility of the pesticides. Typically, most pesticides currently used on corn and soybeans are water soluble and enter aquatic systems predominantly in the dissolved state. Some common examples include alachlor, atrazine, and metolachlor. Because

**Table 8.** Summary of seasonal Kendall trend analysis of nitrite plus nitrate loads at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[ton/d, tons per day; (mg/L)/yr, milligrams per liter per year; **results in bold** are significant with p-values less than or equal to 0.05; <, less than]

Monitoring site number (fig. 1)	Site name	Median nitrite plus nitrate load (ton/d)	Kendall tau	p-value	Trend slope [(mg/L)/yr]
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	1.0	0	1.0000	<0.00001
2	Cedar River near Austin, Minnesota	1.3	<b>.24</b>	<b>.0007</b>	<b>+.0660</b>
3	Cedar River near Charles City, Iowa	6.4	-.11	.2266	-.1482
4	Shell Rock River near Gordonsville, Minnesota	.12	0	1.0000	<.00001
5	West Fork Cedar River near Finchford, Iowa	6.1	.23	.0895	.6642
6	Cedar River at Cedar Falls, Iowa	30.2	<b>.32</b>	<b>.0010</b>	<b>+2.638</b>
7	Cedar River at Gilbertville, Iowa	28.4	<b>.31</b>	<b>.0378</b>	<b>+2.294</b>
8	Cedar River near Palo, Iowa	49.6	<b>-.30</b>	<b>.0207</b>	<b>-5.902</b>
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	16.9	.14	.0924	.6422
10	Iowa River at Iowa City, Iowa	15.7	<b>.19</b>	<b>.0102</b>	<b>+.6925</b>
11	English River near Riverside, Iowa	3.7	.03	.8362	.0059
12	Iowa River at Columbus Junction, Iowa	<sup>1</sup> 26.7	<b>.30</b>	<b>.0530</b>	<b>+4.255</b>
13	Iowa River at Wapello, Iowa	<sup>2</sup> 147.4	.05	.5886	1.979
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	.16	0	1.0000	<.00001
15	South Skunk River near Cambridge, Iowa	3.6	.17	.3615	.2536
16	Cedar Creek near Oakland Mills, Iowa	.84	.16	.2501	.0263
17	Skunk River at Augusta, Iowa	27.4	-.03	.7190	-.1032

<sup>1</sup>Load calculated from Iowa River streamflow upstream from confluence with the Cedar River.

<sup>2</sup>Load calculated from Iowa River streamflow downstream from confluence with the Cedar River.

**Table 9.** Summary of seasonal Kendall trend analysis of ammonia loads at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[ton/d, tons per day; (mg/L)/yr, milligrams per liter per year; **results in bold** are significant with p-value less than or equal to 0.05; <, less than]

Monitoring site number (fig. 1)	Site name	Median ammonia load (ton/d)	Kendall tau	p-value	Trend slope [(mg/L)/yr]
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	0.12	0	1.0000	<0.00001
2	Cedar River near Austin, Minnesota	.31	<b>–.26</b>	<b>.0003</b>	<b>–.0116</b>
3	Cedar River near Charles City, Iowa	.13	<b>–.20</b>	<b>.0403</b>	<b>–.0046</b>
4	Shell Rock River near Gordonsville, Minnesota	.01	0	1.0000	<.00001
5	West Fork Cedar River near Finchford, Iowa	.06	.25	.0643	.0057
6	Cedar River at Cedar Falls, Iowa	.30	.04	.6950	.0026
7	Cedar River at Gilbertville, Iowa	.34	–.10	.5139	–.0041
8	Cedar River near Palo, Iowa	.65	<b>–.45</b>	<b>.0004</b>	<b>–.0795</b>
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	.36	.04	.6310	.0025
10	Iowa River at Iowa City, Iowa	.59	–.09	.2321	–.0103
11	English River near Riverside, Iowa	.07	<b>.27</b>	<b>.0495</b>	<b>+ .0081</b>
12	Iowa River at Columbus Junction, Iowa	<sup>1</sup> .92	–.12	.4389	–.0522
13	Iowa River at Wapello, Iowa	<sup>2</sup> 1.5	–.09	.2971	–.0224
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	.13	0	1.0000	<.00001
15	South Skunk River near Cambridge, Iowa	.03	.22	.2134	.0036
16	Cedar Creek near Oakland Mills, Iowa	.01	<b>.42</b>	<b>.0014</b>	<b>+ .0032</b>
17	Skunk River at Augusta, Iowa	.50	–.06	.5074	–.0038

<sup>1</sup>Load calculated from Iowa River streamflow upstream from confluence with the Cedar River.

<sup>2</sup>Load calculated from Iowa River streamflow downstream from confluence with the Cedar River.

most pesticides are dissolved, their distribution in an aquatic system is determined by water movement. In contrast, hydrophobic (or lipophilic) pesticides have a strong affinity for fats or other organic compounds in the sediment and lack an affinity for water. Hydrophobic pesticides generally are not found in surface water at high concentrations because of their low solubility in the aqueous phase (Larson and others, 1997). Well-known examples of hydrophobic pesticides are the organochlorine insecticides such as chlordane, DDT, and dieldrin. Many organochlorine pesticides have been banned because of their persistence in the environment, their tendency to bioaccumulate, and their toxicity to wildlife. Data for the organochlorine compounds analyzed in stream-water samples were not included in this report as the water analyses were sporadic, missing, or generally at low detection levels. Low detections of dissolved

organochlorine compounds in water are not unusual as the largest environmental sinks for organochlorine compounds are typically in sediment and the lipids of biota.

## Concentrations

Table 11 (p. 54) lists the pesticides that were analyzed and included in the data sets for this study and the amount applied in Iowa (if data were available) based on 1995 agricultural statistics (Sands and Holden, 1996). It was assumed that these amounts reflect relative application rates within the study unit. The amounts of commonly used pesticides, such as acetochlor, atrazine, cyanazine, and metolachlor, applied are almost an order of magnitude higher than other pesticides such as bentazon, 2, 4-D, metribuzin, and trifluralin (table 11, p. 54). Historically, the

application of alachlor, atrazine, cyanazine, and metolachlor has accounted for approximately 70 percent or more of the total amount of pesticides applied in Iowa (Hallberg and others, 1996).

The application of acetochlor to agricultural lands is a recent development (registered in Iowa in 1994) and was not analyzed in the water samples used for this report. The use of acetochlor in Iowa since 1994 has increased greatly, and the use of alachlor has declined. Acetochlor was anticipated as controlling a broader spectrum of weeds than alternative corn herbicides (U.S. Environmental Protection Agency, 1994). Acetochlor applications in Iowa have increased from 4.8 percent of total amount applied in 1994 to 15.4 percent of total amount applied in 1995, whereas alachlor applications declined from 15.9 percent of

total amount applied in 1990 to 1.9 percent of total amount applied in 1995 (Hallberg and others, 1996, p. 72). Acetochlor is a likely pesticide for future monitoring in the EIWA study unit.

The pesticides selected for discussion and for statistical analysis were the more commonly used water-soluble pesticides in Iowa since 1980 (alachlor, atrazine, cyanazine, metolachlor, and metribuzin) (table 12, p. 55). Information on other pesticides (ametryn, carbofuran, chlorpyrifos, fonofos, phorate, prometon, propazine, simazine, simetryn, and terbufos) in the selected data sets was rare (less than 20 analyses for each), and there were no detections greater than the minimum reporting level of 0.10 µg/L. Trifluralin was analyzed in 150 samples but was detected only twice (0.10 and 0.55 µg/L). Atrazine

**Table 10.** Summary of seasonal Kendall trend analysis of total phosphorus loads at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[ton/d, tons per day; (mg/L)/yr, milligrams per liter per year; **results in bold** are significant with p-values less than or equal to 0.05; nt, no trend indicated; --, no data]

Monitoring site number (fig. 1)	Site name	Median total phosphorus load (ton/d)	Kendall tau	p-value	Trend slope [(mg/L)/yr]
<b>Cedar River Basin</b>					
1	Cedar River near Lansing, Minnesota	--	--	-	--
2	Cedar River near Austin, Minnesota	0.16	<b>-0.57</b>	<b>0.0217</b>	<b>-0.0251</b>
3	Cedar River near Charles City, Iowa	.27	0	1.0000	nt
4	Shell Rock River near Gordonsville, Minnesota	--	--	--	--
5	West Fork Cedar River near Finchford, Iowa	.12	.23	.1021	nt
6	Cedar River at Cedar Falls, Iowa	1.1	<b>.31</b>	<b>.0012</b>	<b>+.0896</b>
7	Cedar River at Gilbertville, Iowa	1.3	<b>.41</b>	<b>.0067</b>	<b>+.1558</b>
8	Cedar River near Palo, Iowa	2.0	<b>-.44</b>	<b>.0006</b>	<b>-.3105</b>
<b>Iowa River Basin</b>					
9	Iowa River near South Amana, Iowa	--	--	--	nt
10	Iowa River at Iowa City, Iowa	.15	0	1.0000	nt
11	English River near Riverside, Iowa	.08	.17	.2629	nt
12	Iowa River at Columbus Junction, Iowa	<sup>1</sup> 1.6	.26	.0935	nt
13	Iowa River at Wapello, Iowa	<sup>2</sup> 6.1	0	1.0000	nt
<b>Skunk River Basin</b>					
14	South Skunk River near Ames, Iowa	.15	0	1.0000	nt
15	South Skunk River near Cambridge, Iowa	.18	-.11	.5615	nt
16	Cedar Creek near Oakland Mills, Iowa	.03	<b>.32</b>	<b>.0209</b>	<b>+.0056</b>
17	Skunk River at Augusta, Iowa	1.5	-.26	.5320	nt

<sup>1</sup>Load calculated from Iowa River streamflow upstream from confluence with the Cedar River.

<sup>2</sup>Load calculated from Iowa River streamflow downstream from confluence with the Cedar River.

**Table 11.** Pesticides analyzed and included in U.S. Geological Survey data sets, 1984–95, and amounts of pesticide applied in Iowa during 1995

[CAS number, Chemical Abstract Service registry number; --, no data]

Pesticide name	Chemical class	CAS number	Amount applied <sup>1</sup> (1,000 pounds)	Use
<b>Corn herbicides</b>				
2,4-D	Chlorophenoxy acid	94–75–7	645	Post-emergence control of annual broadleaf weeds.
Acetochlor	Acetamide	34256–82–1	6,205	Pre-emergence, early post-emergence, or pre-plant incorporated control of most annual grasses and broadleaf weeds.
Alachlor	Chloracetamide	15972–60–8	766	Pre- and post-emergence control of most annual grasses and many broadleaf weeds.
Atrazine	Triazine	1912–24–9	6,490	Pre- and post-emergence control of most annual grasses and broadleaf weeds. Used in combination with many other herbicides.
Bentazon	Benzothiadiazole	25057–89–0	207	Post-emergence control of broadleaf weeds.
Cyanazine	Triazine	21725–46–2	5,296	Control of annual grasses and broadleaf weeds. Used with many other herbicides.
Dicamba	Benzoic acid	1918–00–9	1,373	Control of annual grasses and broadleaf weeds. Used with many other herbicides.
Metolachlor	Chloracetamide	51218–45–2	8,374	Post-emergence control of broadleaf weeds and some grasses.
Metribuzin	Triazine	21087–64–9	22	Pre- and post-emergence control of broadleaf weeds and grasses.
<b>Soybean herbicides</b>				
2,4-D	Chlorophenoxy acid	94–75–7	509	Post-emergence control of annual broadleaf weeds.
Bentazon	Benzothiadiazole	25057–89–0	873	Post-emergence control of annual broadleaf weeds.
Thifensulfuron	Triazine	79277–27–3	5	Post-emergence control of annual broadleaf weeds.
Trifluralin	Trifluoromethyl; dinitroaniline	1582–09–8	2,436	Pre-emergence control of many annual grasses and broadleaf weeds.
<b>Other pesticides</b>				
Ametryn	Triazine	834–12–8	--	Herbicide used on cropland and noncropland. Pre- and post-emergence control of annual grasses and broadleaf weeds.
Carbofuran	Carbamate	1563–66–2	--	Insecticide used on corn and soybeans. Control of soil-dwelling and foliar-feeding insects.
Chlorpyrifos	Organophosphorus; pyridine	2921–88–2	--	Insecticide used on cropland and in households. Control of soil insects as well as household pests (ants, cockroaches, flies).
Fonofos	Organophosphorus	944–22–9	--	Soil insecticide used on cropland to control soil insects.
Phorate	Organophosphorus	298–02–2	--	Insecticide used on corn and soybeans. Control of sucking and chewing insects, mites, and soil-dwelling pests.
Prometryn	Triazine	7287–19–6	--	Herbicide used on cropland. Control of annual grasses and broadleaf weeds.
Prometon	Triazine	1610–18–0	--	Herbicide used on noncropland. Control of annual and perennial broadleaf weeds, grasses, and brush.
Propazine	Triazine	139–40–2	--	Herbicide used on sorghum. Pre-planting or pre-emergence control of grasses and broadleaf weeds.
Simazine	Triazine	122–34–9	--	Herbicide used on fruit. Control of germinating annual grasses and broadleaf weeds.
Simetryn	Triazine	1014–70–6	--	Herbicide used on rice. Used in combination with thiobencarb to control broadleaf weeds.

<sup>1</sup>Data from Sands and Holden (1996).

was detected at all monitoring sites, with larger median concentrations (0.20 to 0.46 µg/L) when compared to the other pesticides (table 12). Concentrations of pesticides often are large (0.56 to 31 µg/L) during spring runoff. Typically, the USEPA MCL for atrazine (3 µg/L) is exceeded during spring runoff at the monitoring sites.

### Seasonal and Annual Variability

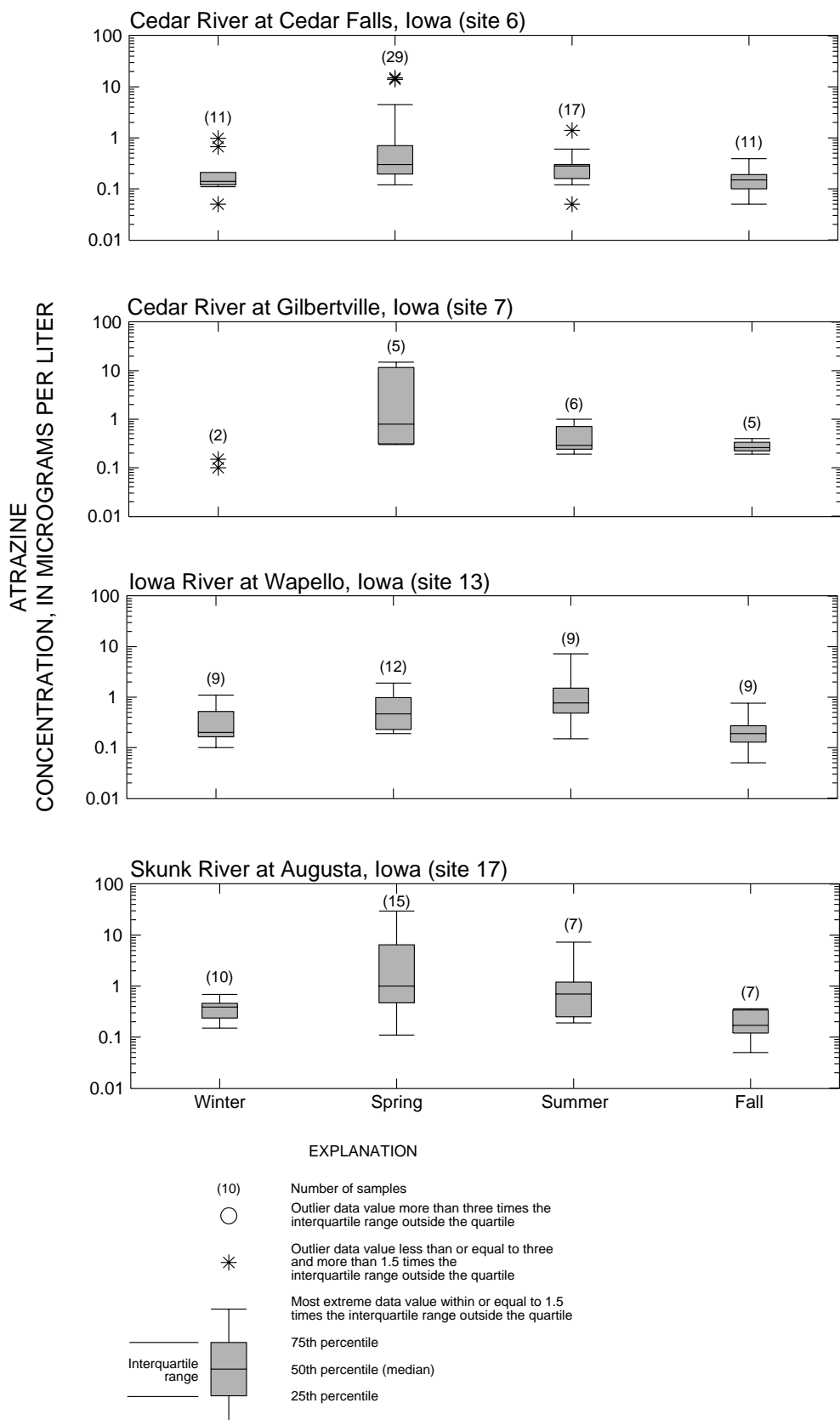
Pesticides in the EIWA study unit generally are applied during short seasonal periods. For example, pre-emergent herbicides are applied just before planting, and post-emergent herbicides are applied a few weeks after the crop germinates. The

seasonal pattern of occurrence for common herbicides such as alachlor and atrazine and in Midwestern rivers has been studied extensively (Richards and Baker, 1991; Goolsby and Battaglin, 1993). Concentrations are generally low in the late fall and winter and peak in the spring and early summer. Herbicide data from monitoring sites in the EIWA study unit follow this trend (fig. 25), with atrazine being the most commonly detected pesticide. The major application of herbicides in the EIWA study unit starts in late April to mid-May. Increased concentrations of herbicides in streams draining agricultural areas can occur within a few days to a few weeks, depending on the timing and number of rainfall events and the size of the drainage basin

**Table 12.** Statistical summary for selected pesticides at surface-water-quality monitoring sites in the Eastern Iowa Basins study unit, 1970–95

[µg/L, micrograms per liter; <, less than]

Constituent	Number of samples	Minimum concentration measured (µg/L)	Percentile			Maximum concentration measured (µg/L)	Mean concentration measured (µg/L)
			25	50 (median)	75		
Cedar River at Cedar Falls, Iowa (site 6, fig. 1)							
Alachlor	68	<0.10	<0.10	<0.10	<0.10	22	0.57
Atrazine	68	<.10	.14	.20	.40	15	.86
Cyanazine	68	<.20	<.20	<.20	.30	9.3	.49
Metolachlor	68	<.10	<.10	<.10	.20	11	.55
Metribuzin	55	<.10	<.10	<.10	<.10	2.4	.15
Cedar River at Gilbertville, Iowa (site 7, fig. 1)							
Alachlor	17	<.10	<.10	<.10	.30	17	1.4
Atrazine	18	.10	.26	.29	.63	15	1.7
Cyanazine	17	<.20	<.20	<.20	<.20	7.6	.84
Metolachlor	17	<.10	<.10	<.10	.38	11	1.2
Metribuzin	17	<.10	<.10	<.10	<.10	2.0	.21
Iowa River at Wapello, Iowa (site 13, fig. 1)							
Alachlor	39	<.10	<.10	<.10	<.10	1.0	.10
Atrazine	39	<.10	.19	.32	.77	7.2	.69
Cyanazine	39	<.20	<.20	<.20	.34	1.3	.25
Metolachlor	39	<.10	<.10	<.10	.31	2.1	.25
Metribuzin	38	<.10	<.10	<.10	<.10	.56	.09
Skunk River at Augusta, Iowa (site 17, fig. 1)							
Alachlor	39	<.10	<.10	<.10	.14	8.9	.47
Atrazine	39	<.10	.25	.46	1.2	30	2.5
Cyanazine	39	<.20	<.20	<.20	.80	31	2.5
Metolachlor	39	<.10	<.10	.11	.68	5.0	.56
Metribuzin	38	<.10	<.10	<.10	<.10	11	.41



**Figure 25.** Atrazine concentrations by season at selected sites in the Eastern Iowa Basins study unit.

(Larson and others, 1997). Typically, smaller tributaries have more strongly skewed distributions and much greater temporal variability in concentrations than do larger rivers (Baker, 1988). Pesticide concentrations in the study unit generally increase with increasing streamflow and decrease with decreasing streamflow. Relatively high monthly mean concentrations are usually observed from May through July, and low concentrations are present during the rest of the year. Concentrations of atrazine observed in the winter months may be sourced from bank or ground-water storage (Squillace and others, 1993). The mean concentrations of alachlor and atrazine generally exceeded the USEPA MCLs at least once annually, but the other herbicides did not exceed the MCLs (for the few herbicides that have had MCLs established).

The pesticide data summarized in this report typically were collected quarterly; therefore, it was not appropriate to use the seasonal Kendall tau test to identify long-term trends. Monthly data are needed for accurate trend testing. However, plots of pesticide concentrations and streamflow were completed for atrazine, cyanazine, metolachlor, alachlor, and metribuzin for the Cedar River at Gilbertville (site 7), Iowa River at Wapello (site 13), and Skunk River at Augusta (site 17) (figs. 26–28). No long-term trends are apparent because of the short timeframe of the data sets.

The seasonal peaks in concentration are affected strongly by the timing of rainfall with respect to application so that annual variability at specific sampling sites can be quite large (figs. 26–28). For example, atrazine in the Skunk River at Augusta (site 17) had concentration peaks that ranged from less than 2 µg/L to more than 10 µg/L between successive years (fig. 26). Although streamflow does affect water-soluble pesticide concentrations, the timing of runoff is more likely to affect concentrations in the river. A large streamflow during late summer may be associated with rather low concentrations of pesticides, but small streamflows during the spring can have high pesticide concentrations. Potentially large quantities of pesticides can be transported to surface water by the first runoff-inducing rainfall following pesticide application (Goolsby and Battaglin, 1993; Larson and others, 1997). Monthly long-term monitoring of pesticide concentrations would be important in obtaining a complete understanding of pesticide concentrations over a range of streamflow conditions.

## IMPLICATIONS FOR DATA COLLECTION AND ANALYSIS

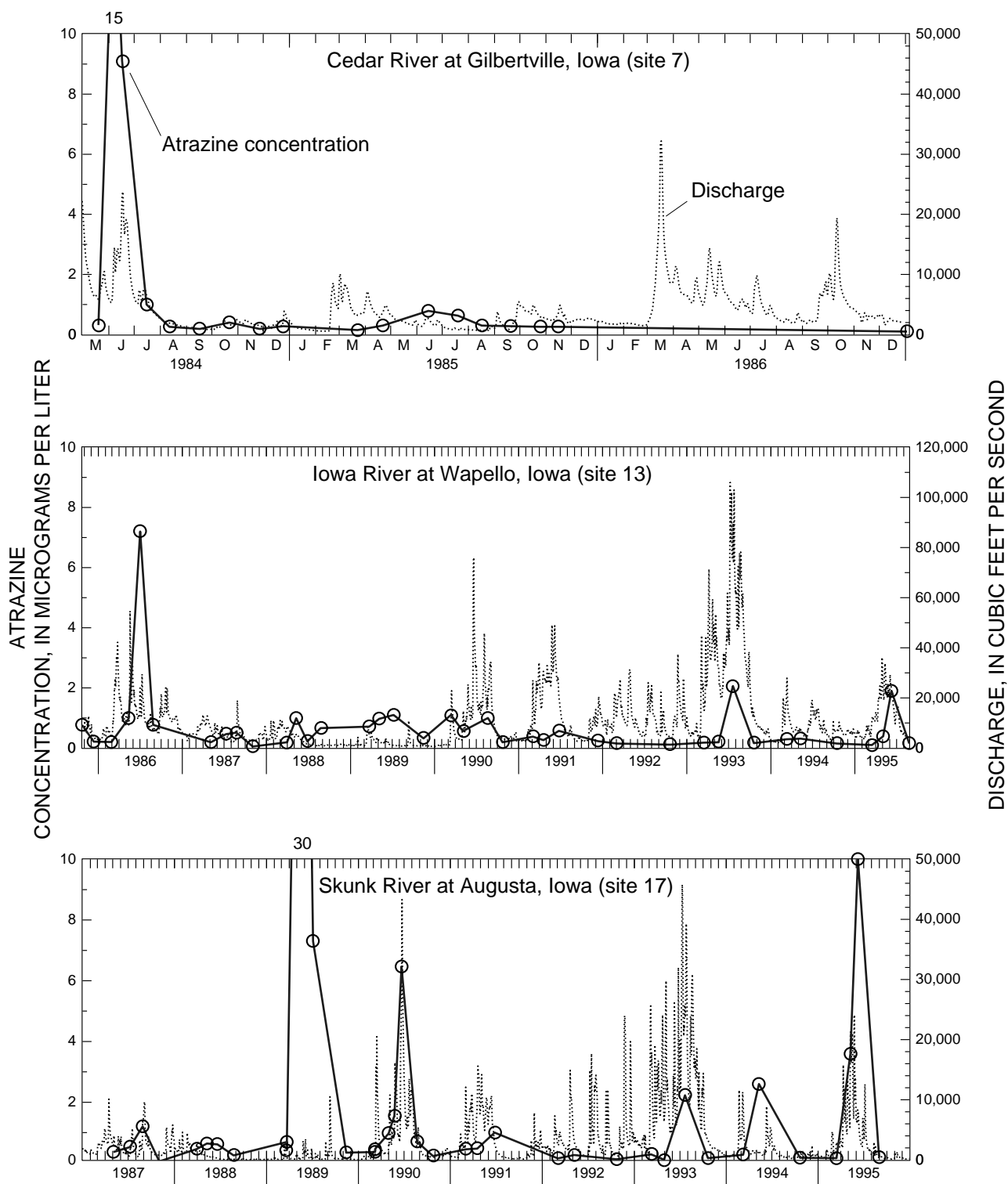
The assessment of available surface-water-quality data from 1970 to 1995 provided valuable information on nutrients and pesticides and possible trends. In addition, the analysis of the historical data illustrated areas where future work may be important or identified areas where additional data are needed to aid water-supply planners, managers, and surface-water users.

Most of the surface-water-quality data analyzed in this assessment were collected from monitoring sites on large rivers. Information on smaller river basins (200 to 700 mi<sup>2</sup>) would facilitate the assessment of natural factors (steepness of slopes, soil types, and infiltration). Smaller river basins may show greater extremes and fluctuations that may be missed by analyzing only larger river basins. Analysis of smaller river basins may be the first indicator for trends that could develop in the larger river basins. Smaller river basins (assuming similar land use) may be used as a microcosm of what is happening at a larger scale. Comparisons between smaller river basins (assuming similar land use) might identify any spatial trends between basins.

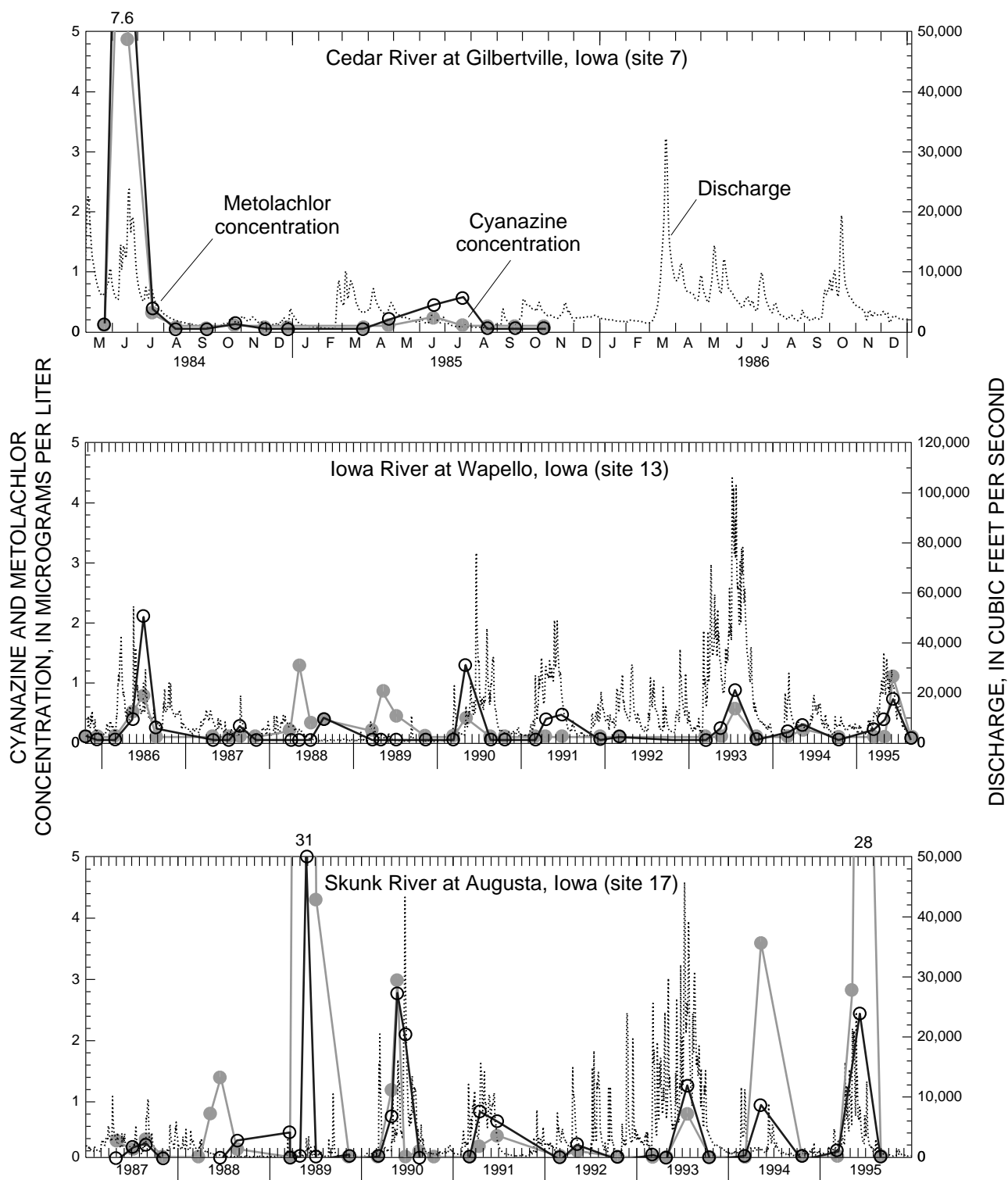
Much of the water-quality data collected in the EIWA study unit have been used to address the specific needs of various programs or research studies. Consequently, water-quality data often are diverse in constituents and properties measured, sample-collection protocols, analytical methods, and sampling frequency. The monitoring sites with 10 or more years of water-quality data were the most important in defining possible trends. Consistent, long-term monitoring is critical in identifying trends and in determining if water quality is improving, degrading, or remaining unchanged with time.

Identifying areas of high phosphorus enrichment from years of fertilizer application may be useful in determining phosphorus transport to streams. Nitrogen species often are transported through base flow. Tile drains may be an important transport mechanism for nitrogen species to surface water. The effect of tile drains in the role of nitrogen transport to streams in the study unit is relatively unstudied.

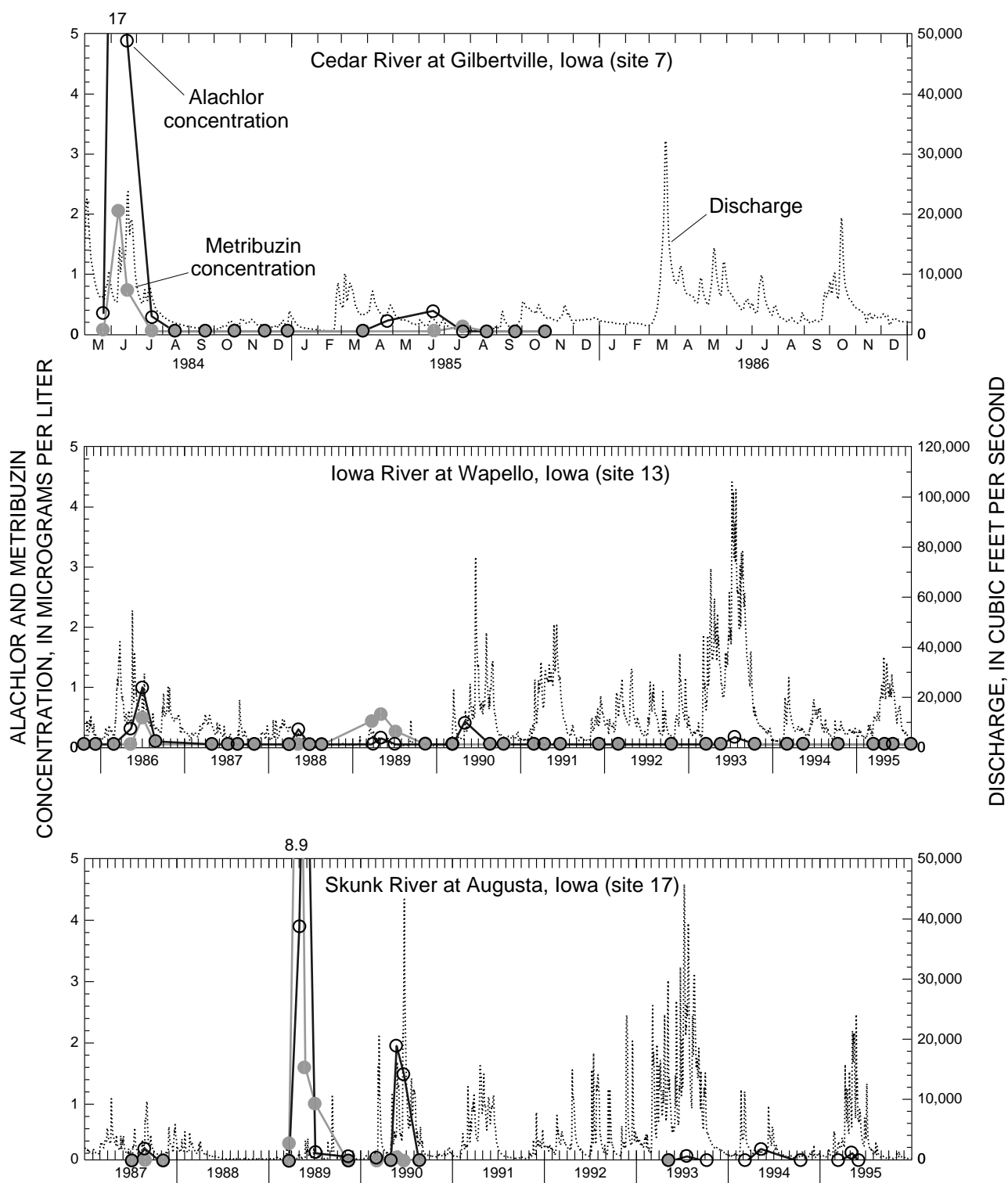
There are numerous hog-production facilities that have begun operation in the 1990's in the study unit. In particular, the upper parts of the Iowa River



**Figure 26.** Atrazine concentrations at selected sites in the Eastern Iowa Basins study unit.



**Figure 27.** Cyanazine and metolachlor concentrations at selected sites in the Eastern Iowa Basins study unit.



**Figure 28.** Alachlor and metribuzin concentrations at selected sites in the Eastern Iowa Basins study unit.

and Skunk River Basins have had more than twice the number of hog facilities permitted from 1993–96 compared to 1987–93. The potential negative effects of these hog-production facilities on surface-water quality may be of concern.

Surface-water samples are needed to characterize water-quality variations associated with changes in season and streamflow. Typically, monthly samples are needed to measure the effects of seasonal fluctuations. Monthly samples at monitoring sites used in this report would provide extremely valuable data to determine seasonal trends in water quality and streamflow. Monthly samples also are important for understanding long-term trends. Sampling that targets storm runoff would measure the effects of nonpoint-source pollution from urban and agricultural areas and improve constituent load estimates. Substantial loads of nutrients and herbicides can be carried by streams during runoff (Schottler and others, 1994; Larson and others, 1997).

The Cedar River had the most extensive surface-water-quality data set in the study unit. However, monthly long-term data for the Wapsipinicon River were lacking. The Wapsipinicon River is one of the major rivers in eastern Iowa, but very little historical data are available. Preliminary data indicate that the Wapsipinicon River may have a larger riparian zone than other large rivers in the study unit. A larger riparian zone may help to reduce the transport of nutrients and pesticides to the river. Data on the Wapsipinicon River would be valuable for a comparison with the Cedar River or other large rivers.

Long-term monitoring data for pesticides are lacking in the EIWA study unit. Pesticide concentrations fluctuate annually, depending on a variety of factors including application rates, rainfall, runoff rates, and timing of runoff after application. Long-term monitoring is important in determining if pesticide concentrations are increasing. It was not possible to analyze long-term temporal or spatial pesticide trends due to the lack of data available. In addition, pesticide metabolites (degradation products of pesticides) may persist at higher concentrations than the parent compounds (Kalkhoff and others, 1998). Data to monitor trends in pesticide and pesticide metabolite concentrations are basic to determining the occurrence and fate of these compounds.

## SUMMARY

In 1991, the U.S. Geological Survey (USGS) began implementation of the National Water-Quality Assessment (NAWQA) Program. The Eastern Iowa Basins (EIWA) study unit was selected as one of the units that began work in 1994. The Eastern Iowa Basins study unit encompasses 19,500 mi<sup>2</sup> and is divided into four main subbasins—the Wapsipinicon, Cedar, Iowa, and Skunk. This report compiled selected nutrient and pesticide data in the Eastern Iowa Basins study unit from the period 1970–95 and described, to the extent possible, patterns and trends.

Seventeen surface-water-quality monitoring sites were selected where monthly sampling data were available with a long-term record (5 years or greater). Water-quality data were compiled for seven monitoring sites sampled by the Iowa Department of Natural Resources, three sampled by the Minnesota Pollution Control Agency, three sampled by the University of Iowa Institute for Hydraulic Research, and four sampled by the U.S. Geological Survey. Streamflow data were available or estimated from nearby stream gages for 12 of the 17 surface-water-quality monitoring sites. The water-quality analyses typically consisted of nitrate, ammonia, total nitrogen, and total phosphorus, with limited analyses available for organic nitrogen, dissolved phosphorus, dissolved orthophosphate, and water-soluble pesticides. The Cedar River and two of its tributaries had the most monitoring sites (eight), including some with the longest periods of record available (20 years). In contrast, monthly water-quality data for the Wapsipinicon River were scant or not available. Long-term pesticide data were lacking for most monitoring sites in the Eastern Iowa Basins study unit.

A statistical analysis of the nutrient data was summarized for each monitoring site. The median concentrations for total nitrogen ranged from 4.6 to 9.4 mg/L, and maximum concentrations of total nitrogen ranged from 4.6 to 31 mg/L. Median concentrations of total phosphorus ranged from less than 0.10 to 0.66 mg/L, and maximum concentrations of total phosphorus ranged from less than 0.10 to 5.4 mg/L. Median concentrations of nitrate were largest during the spring and winter (6.0 to 7.0 mg/L) and smallest in the summer and fall (2.0 to 4.0 mg/L).

Concentrations of nitrate greater than 10 mg/L typically occurred during spring runoff. The largest nitrate concentration was 26 milligrams per liter nitrate as nitrogen in the Shell Rock River near Gordonsville, Minnesota. Median ammonia concentrations generally were greatest during the winter (approximately 0.3 to 0.5 mg/L) compared to the spring and summer when ammonia concentrations often were close to the detection limit (0.01 mg/L). In general, the median concentrations of total phosphorus varied less than 0.1 mg/L between seasons.

Nitrate concentrations were strongly correlated with streamflow. Total phosphorus showed a weak positive correlation with streamflow with more variability than nitrate concentrations. The trend line for nitrate concentration with increasing streamflow was steeper than the trend line for total phosphorus at low and moderate streamflows. Nitrate is generally transported in the dissolved phase by overland flow, tile drains, interflow, and ground-water discharge. In contrast, the transport of phosphorus often is associated with sediment and not in the dissolved phase.

The ammonia and ammonia plus organic nitrogen concentrations were not correlated with streamflow or indicated a weak positive correlation. This is expected as the concentrations of these nitrogen species are small to begin with and are oxidized rather quickly by instream processes. The trend lines showed differences between point and non-point sources. Nitrate and phosphorus concentrations increased with decreasing streamflow during low-flow conditions.

Seasonal Kendall statistical trend analysis of nutrient concentrations generally indicated decreases for ammonia and total phosphorus concentrations with increases for nitrate concentrations for other sites in the study unit. Ammonia nitrogen reductions are most likely the result of improvements to wastewater-treatment plants in the late 1980's. In general, the median concentrations of total phosphorus varied less than 0.1 mg/L between seasons. Total phosphorus concentrations did not show a strong seasonal variation when compared to nitrate concentrations. An increase in nitrate concentration across the study unit was apparent after the 1988–89 drought because of leaching and subsequent transport of nitrogen that had accumulated in the soil.

The seasonal Kendall statistical trend analysis for instantaneous loads (concentration multiplied by streamflow at the time of sample) also were completed

for sites where streamflow data were available or could be estimated from nearby stream gages. Instantaneous load trends for total phosphorus showed three sites with upward trends (Cedar River at Cedar Falls, Cedar River at Gilbertville, and Cedar Creek near Oakland Mills) and two sites with downward trends (Cedar River near Austin, Minnesota, and Cedar River near Palo, Iowa). Instantaneous load trends for ammonia were noted at two sites (English River near Riverside and Cedar Creek near Oakland Mills) with downward trends at three sites (Cedar River near Austin, Cedar River near Charles City, and Cedar River near Palo). Nitrate instantaneous load trends showed increases at five sites (Cedar River near Austin, Cedar River at Cedar Falls, Cedar River at Gilbertville, Iowa River at Iowa City, and Iowa River at Columbus Junction) and a decrease at one site (Cedar River near Palo). Numerous factors such as soil conditions, increased soil “loading” of nitrate or phosphorus, livestock facilities, and wastewater-treatment plants can affect long-term trends.

Data on water-soluble pesticides were not as complete as the nutrient data sets. Long-term pesticide data are lacking in the study unit. Statistical summaries were completed for the most commonly detected pesticides—alachlor, atrazine, cyanazine, metolachlor, and metribuzin. Other pesticides in the data sets had concentrations that were not detected or had values at or less than the analytical method detection level. Atrazine was the most commonly detected pesticide. Maximum concentrations of pesticides usually occurred after spring runoff. The largest pesticide concentration was 31 micrograms per liter for cyanazine in a sample from the Skunk River at Augusta. However, mean concentrations of pesticides were typically less than the maximum contaminant levels. Large streamflows during the late summer do not have pesticide concentrations as large as do the streamflows during the spring that occur soon after the application of pesticides.

In general, when analyzing the seasonal variations of nutrients and pesticides concentrations and the relations of nutrients and pesticides concentrations to streamflow, the available information generally corresponded with nonpoint-source loadings. However, possible point sources for nutrients were indicated by at selected monitoring sites, particularly those downstream from wastewater-treatment plants.

## REFERENCES

- Alexander, R.B., and Smith, R.A., 1990, County-level estimates of nitrogen and phosphorus fertilizer use in the United States, 1945 to 1985: U.S. Geological Survey Open-File Report 90-130, 12 p.
- Allen, J.D., 1995, Stream ecology—Structure and function of running waters: New York, Chapman and Hall Publishers, 388 p.
- American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1976, Standard methods for the examination of water and wastewater (14th ed.): American Public Health Association, New York, New York.
- Baker, D.B., 1988, Sediment, nutrient and pesticide transport in selected lower Great Lakes tributaries: Chicago, Illinois, Great Lakes National Program Office, Report number 1, U.S. Environmental Protection Agency, EPA-905/4-88-001, 225 p.
- Bonn, B.A., Wentz, D.A., and Hinkle, S.R., 1996, Nitrogen in streams and ground water, 1980-1990, Willamette Basin, Oregon: U.S. Geological Survey Open-File Report 96-227, 4 p.
- Brezonik, P.L., 1973, Nitrogen sources and cycling in natural waters: U.S. Environmental Protection Agency, Office of Research and Development, EPA-660/3-73-002, 167 p.
- Buchmiller, Robert, Gaillot, Gary, and Soenksen, P.J., 1985, Water resources of north-central Iowa: State of Iowa, Iowa Geological Survey Water Atlas Number 7, 93 p.
- Cleveland, W.S., 1979, Robust locally weighted regression and smoothing scatterplots: *Journal of American Statistics Association*, v. 74, p. 829-836.
- Colborn, Theo, and Clement, C.R., eds., 1992, Chemically-induced alterations in sexual and functional development—The wildlife/human connection: Princeton, N.J., Princeton Publishing, *Advances in Modern Environmental Toxicology series*, v. 21, 403 p.
- Colborn, Theo, Vom Saal, F.S., and Soto, A.M., 1993, Developmental effects of endocrine disrupting chemicals in wildlife and humans: *Environmental Health Perspectives*, v. 101, p. 378-384.
- Crumpton, W.G., and Isenhardt, T. M., 1987, Nitrogen mass balance in streams receiving secondary effluent—The role of algal assimilation: *Journal of the Water Pollution Control Federation*, v. 59, no. 9, p. 821-824.
- Eash, D. A., 1993, Estimating design-flood discharges for streams in Iowa using drainage-basin and channel-geometry characteristics: U.S. Geological Survey Water-Resources Investigations Report 93-4062, 96 p.
- Fischer, E.E. and Eash, D.A., 1998, Statistical summaries of selected Iowa streamflow data through September 30, 1996: U.S. Geological Survey Open-File Report 98-170, 681 p.
- Gburek, W.J., and Sharpley, A.N., 1998, Hydrologic controls on phosphorus loss from upland agricultural watersheds: *Journal of Environmental Quality*, v. 27, p. 267-277.
- Gebert, W.A., Graczyk, D.J., and Krug, W.R., 1987, Average annual runoff in the United States, 1951-80: U.S. Geological Survey Hydrologic Investigations Atlas HA-710, 1 sheet, scale 1:7,500,000.
- Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.
- Goodbred, S.L., Gilliom, R.J., Gross, T.S., Denslow, N.P., Wade, B.B., and Schoeb, T.R., 1997, Reconnaissance of 17b-estradiol, 11-ketotestosterone, vitellogenin, and gonad histopathology in common carp of United States streams—Potential for contaminant-induced endocrine disruption: U.S. Geological Survey Open-File Report 96-627, 47 p.
- Goolsby, D.A., and Battaglin, W.A., 1993, Occurrence, distribution, and transport of agricultural chemicals in surface water of the Midwestern United States, *in* Goolsby, D.A., Boyer, L.L., and Mallard, G.E., compilers, *Selected papers on agricultural chemicals in water resources of the midcontinental United States*: U.S. Geological Survey Open-File Report 93-418, p. 1-25.
- Goolsby, D.A., Coupe, R.C., and Markovchick, D.J., 1991, Distribution of selected herbicides and nitrate in the Mississippi River and its major tributaries, April through June, 1991: U.S. Geological Survey Water-Resources Investigations Report 91-4163, 35 p.
- Griffith, G.E., Omernik, J.M., Wilton, T.F., and Pierson, S.M., 1994, Ecoregions and subregions of Iowa—A framework for water quality assessment and management: *Journal of the Iowa Academy of Science*, p. 5-13.
- Hallberg, G.R., 1989, Nitrate in groundwater in the United States, *in* Follett, R. F., ed., *Nitrogen management and groundwater protection*: Amsterdam, The Netherlands, Elsevier Science Publishers, chapter 3, p. 35-74.
- Hallberg, G.R., Riley, D.G., Kantamneni, J.R., Weyer, P.J., and Kelley, R.D., 1996, Assessment of Iowa safe drinking water act monitoring data, 1988-1995: Iowa City, University of Iowa Hygienic Laboratory Research Report No. 97-1, 132 p.
- Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier Science Publishers, 522 p.
- Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

- Hirsch, R.M., Slack, J.R., and Smith, R.A., 1982, Techniques of trend analysis for monthly water quality data: *Water Resources Research*, v. 18, no. 1, p. 107–121.
- Iowa Department of Natural Resources, 1994a, Water quality in Iowa during 1992 and 1993: Iowa Environmental Protection Division, Water Resources Section 305(b) Report, 226 p.
- 1994b, Quality assurance/work plan for Iowa's fixed station and rotational cyclic water quality monitoring networks for 1994 through 2000: Iowa Department of Natural Resources Environmental Protection Division, 32 p.
- 1994c, Wastewater treatment plants in Iowa: accessed November 19, 1998, at URL <http://www.igsb.uiowa.edu/nrgis/enviro.idc#default>, coverage called wwtp.
- Iowa Department of Natural Resources, 1998a, Confinement feeding operations: accessed January 12, 1998, at URL <http://www.state.ia.us/government/dnr/organiza/epd/wastewtr/feedlot/feedlt.htm>
- Iowa Department of Natural Resources, 1998b, Animal waste control facilities with operating permits in Iowa: accessed November 19, 1998 at URL <http://www.igsb.uiowa.edu/nrgis/enviro.idc#default>, coverage called agdfac.
- Justic, D., Rabalais, N.N., Turner, E.R., and Wiseman, W.J., 1993, Seasonal coupling between riverborne nutrients, net productivity, and hypoxia: *Marine Pollution Bulletin*, v. 26, no. 4, p. 184–189.
- Kalkhoff, S.J., 1993, Water quality of Corydon Reservoir before implementation of agricultural best-management practices in the basin, Wayne County, Iowa, September 1990 to September 1991: U.S. Geological Survey Water-Resources Investigations Report 93–4099, 36 p.
- 1994, National Water-Quality Assessment Program—Eastern Iowa Basins: U.S. Geological Survey Fact Sheet FS–94–031, 1 p.
- Kalkhoff, S.J., Kolpin, D.W., Thurman, E.M., Ferrer, I. and Barcelo, D., 1998, Degradation of chloroacetanilide herbicides: The prevalence of sulfonic and oxanilic acid metabolites in Iowa ground waters and surface waters: *Environmental Science and Technology*, v. 32, no. 11, p. 1738–1740.
- Kendall, M.G., 1975, Rank correlation methods (4th ed.): London, Great Britain, Charles Griffin, 202 p.
- Larson, S.J., Capel, P.D., and Majewski, M.S., 1997, Pesticides in surface waters, distribution, trends, and governing factors, *in* U.S. Geological Survey National Water-Quality Assessment Program, v. 3—Pesticides in the hydrologic system: Chelsea, Mich., Ann Arbor Press, Inc., 373 p.
- Leahy, P.P., and Wilber, W.G., 1991, National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 91–54, 2 p.
- Libra, R.D., Quade, D.J., and Rieck-Hinz, A., 1996, Agricultural drainage wells and ground-water quality, Hogs, bogs, and logs, *in* Quaternary deposits and environmental geology of the Des Moines Lobe: Geological Survey Bureau Guidebook Series No. 18, North-Central Section Annual Meeting of the Geological Society of America, Field Trip 5, p. 155–170.
- Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S., and Johnson, N.M., 1977, Biogeochemistry of a forested ecosystem: New York, Springer-Verlag, 146 p.
- Logan, T. J., 1978, Maumee River Basin pilot watershed study, *in* International Reference Group on Great Lakes pollution from land use activities: Windsor, Ontario, International Joint Commission, 96 p.
- Lucey, K.J., and Goolsby, D.A., 1993, Effects of climatic variations over 11 years on nitrate-nitrogen concentrations in the Raccoon River, Iowa: *Journal of Environmental Quality*, v. 22, no.1, p. 38–46.
- McLeod, A.I., Hipel, K.W., and Bodo, B.A., 1991, Trend analysis methodology for water quality time series: *Environmetrics*, v. 2, no. 2, p. 169–200.
- Meybeck, Michel, 1982, Carbon, nitrogen and phosphorus transport by world rivers: *American Journal of Science*, v. 282, p. 401–450.
- National Research Council, 1978, Nitrates—An environmental assessment: Washington, D. C., National Academy of Sciences, 723 p.
- Neill, M., 1989, Nitrate concentrations in river waters in the southeast of Ireland and their relationship with agricultural practice: *Water Research*, v. 23, p. 1339–1355.
- Nowell, L.H., and Resek, E.A., 1994, National standards and guidelines for pesticides in water, sediment, and aquatic organisms—Application to water-quality assessments: *Review of Environmental Contaminant Toxicology*, v. 140, p. 1–164.
- O'Connell, D.J., Liszewski, M.J., Lambert, R.B., and Matthes, W.J., 1990, Water resources data, Iowa, water year 1990: U.S. Geological Survey Water-Data Report IA–90–1, 421 p.
- Ott, L.R., 1993, An introduction to statistical methods and data analysis (4th ed.): Belmont, Calif., Duxbury Press of Wadsworth Publishing Company, 1051 p.
- Prior, J.C., 1991, Landforms of Iowa: Iowa City, University of Iowa Press, p. 30–75.
- Rabalais, N.N., Turner, R.E., Justic, D., Dortch, Q., Wiseman, W.J., and Gupta, B.K.S., 1996, Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf: *Estuaries*, v. 19, no. 2b, p. 386–407.
- Richards, R.P. and Baker, D.B., 1991, Pesticide concentration patterns in agricultural drainage networks in the Lake Erie Basin: *Environmental Toxicology and Chemistry*, v. 12, p. 13–26.

- Richards, R.P., Baker, D.B., Christensen, B.R., and Tierney, D.P., 1995, Atrazine exposures through drinking water—Exposure assessments for Ohio, Illinois, and Iowa: *Environmental Science and Technology*, v. 29, p. 406–426.
- Sands, J.K., and Holden, H.R., 1996, Iowa agricultural statistics: Des Moines, Iowa, U.S. Department of Agriculture and Iowa State University Extension to Agriculture, 97 p.
- SAS Institute, Inc., 1989, SAS/STAT User's guide, version 6, 4th ed., volume 2: Cary, N.C., SAS Institute Inc., 846 p.
- Schepers, J.S., and Francis, D. D., 1998, Manure characterization and nutrient utilization strategies for crops to minimize environmental risks: Proceedings of conference on Animal Feeding Operations and Ground Water; issues, impacts, and solutions—A conference for the future, November 4–5, St. Louis, Missouri, p. 96–104.
- Schottler, S.P., Eisenreich, S.J., and Capel, P.D., 1994, Atrazine, alachlor, and cyanazine in a large agricultural river system: *Environmental Science and Technology*, v. 28, no. 6, p. 1079–1089.
- Seigley, L.S., Hallberg, G.R., Rowden, R.D., Libra, R.D., Giglierano, J.D., Quade, D.J., and Mann, K.O., 1993, Agricultural land use and nitrate cycling in surface water in Northeast Iowa: Proceedings, Ankeny, Iowa, Agricultural Research to Protect Water Quality, Soil and Water Conservation Society, p. 85–88.
- Smith, R.A., Hirsch, R.N., and Slack, J.R., 1982, A study of trends in total phosphorus measurements at NASQAN stations: U.S. Geological Survey Water-Supply Paper 2190, 34 p.
- Soenksen P.J., and Eash, D.A., 1991, Iowa, in *National water summary 1988–89—Floods and droughts*, Paulson, R.W., Chase, E.B., Roberts, R.R., and Moody, D.W. (compilers): U.S. Geological Survey Water-Supply Paper 2375, p. 279–286.
- Southard, R.E., Sneek-Fahrer, D.A., Anderson, C.J., Goodrich, R.D., and Gorman, J.G., 1994, Water resources data of Iowa water year 1993: U.S. Geological Survey Water-Data Report IA-93-1, 388 p.
- Squillace, P.J., Thurman, E.M., and Furlong, E.T., 1993, Groundwater as a nonpoint source of atrazine and deethylatrazine in a river during base flow conditions: *Water Resources Research*, v. 29, no. 6, p. 1719–1729.
- U.S. Department of Commerce, 1959, *Climates of the States—Climate of Iowa*: U.S. Government Printing Office, *Climatology of the United States* No. 6013, 2 p.
- U.S. Department of Commerce, Bureau of the Census, 1994, *Census of population and housing, 1990, Public Law 94-171 data (United States)*: Washington, D.C., Bureau of the Census.
- U.S. Environmental Protection Agency, 1972, *Handbook for analytical quality control in water and wastewater laboratories*: Cincinnati, Ohio, Environmental Quality Control Laboratory.
- 1979, *Methods for chemical analysis of water and wastes*: Cincinnati, Ohio, Environmental Monitoring and Support Laboratory.
- 1986, *Quality criteria for water—1986*: Washington, D.C., Office of Water Regulations and Standards, EPA-440/5-86-001, 446 p.
- 1994, *Prevention, pesticides, and toxic substances—Questions and answers, conditional registration of acetochlor*, U.S. EPA: Washington, D.C., March 11, 1994, 18 p.
- University of Iowa Hygienic Laboratory, 1970, *Chemical and bacteriological survey of the Iowa River: Report 70-27*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 10 p.
- 1971, *Cedar River water quality survey: Cedar Falls-Waterloo area: Report 71-22*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 20 p.
- 1976a, *Winter survey of the South Skunk River: Report 76-22*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 10 p.
- 1976b, *Winter water quality survey of the Iowa River: Report 76-25*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 6 p.
- 1977a, *Winter water quality evaluation of the lower Cedar during low flow periods: Report 77-25*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 11 p.
- 1977b, *Winter water quality survey of the Iowa River: Report 77-27*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 10 p.
- 1978, *Winter water quality survey of the Shell Rock River: Report 78-46*, prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 14 p.
- 1988, *IBP—Columbus Junction study, September 1988: Report 88-8* prepared for the Iowa Department of Natural Resources by the University of Iowa Hygienic Laboratory, Iowa City, 15 p.
- Viessman, Warren, Jr., Lewis, G.L., and Knapp, J.W., 1989, *Introduction to hydrology*: New York, Harper and Row Publishers, 780 p.
- Ward, J.R., and Harr, C.A., 1990, *Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses*: U.S. Geological Survey Open-File Report 90-140, 71 p.
- Wetzel, R.G., 1983, *Limnology* (2d ed.): Philadelphia, Saunders College Publishing Co., 767 p.

